

**APPENDIX B & APPENDIX C
FEASIBILITY STUDY
SOUTH CAVALCADE SITE
HOUSTON, TEXAS**

008167

APPENDIX B
DETAILED GENERAL DESCRIPTIONS
OF TECHNOLOGIES
FEASIBILITY STUDY
SOUTH CAVALCADE SITE
HOUSTON, TEXAS

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4.3 OFF-SITE SOIL/RESIDUE DISPOSAL
LANDFILL

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1.0 CONTAINMENT

1.1 IN SITU ISOLATION

SOIL COVER

SURFACE CAPPING

SLURRY TRENCH

GROUT CURTAIN

SHEET PILES

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SOIL COVER
(In Situ Containment)

MEDIUM:

Contaminated soil or buried wastes residue

PROCESS TYPE:

Geotechnical

RELATED SITE EXPERIENCE:

Yes (limited)

APPLICABLE CHEMICALS OF INTEREST:

All chemicals of interest if suitable barrier materials are used.

TECHNOLOGY STATUS:

Established Technology with changing modifications

DESCRIPTION:

Soil Covers are designed to reduce soil erosion and inhibit dermal contact with site soil. A soil cover can be easily implemented with materials available in the site area. An appropriate soil cover could consist of 6 inches of clean (non-stony) fill.

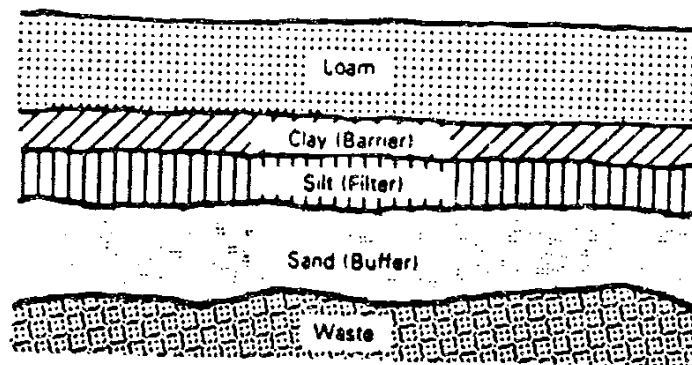
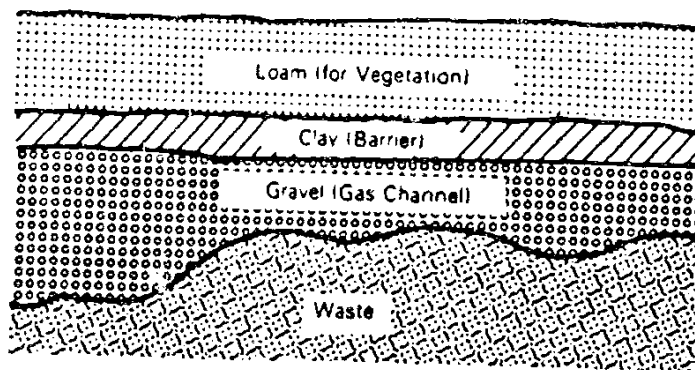
Layering is perhaps the most promising technique for designing a final solid waste cover. This technique entails the use of different materials in distinct layers to utilize their most favorable characteristics to reduce erosion and percolation of surface waters into the waste area. A layered system may include topsoil, a barrier layer, buffer layer, water drainage layer, filter and gas drainage layer.

PERFORMANCE:

Soils composed predominantly of clay are well suited for covers, particularly in humid climates as their permeability is low. However, such soils have a tendency to shrink and crack in dry seasons. This would reduce the covers integrity and effectiveness. Where appropriate soils are available locally, costs can be kept to a minimum over the need to transport material in for construction.

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TWO TYPICAL LAYERED COVER SYSTEMS (Source: Lutton et al., 1979)



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SURFACE CAPPING (In Situ Containment)

MEDIUM:

Contaminated soil or buried wastes/residues

PROCESS TYPE:

Geotechnical

RELATED SITE EXPERIENCE:

Yes (limited)

APPLICABLE CHEMICALS OF INTEREST:

All chemicals of interest if suitable barrier materials are used.

TECHNOLOGY STATUS:

Established technology with changing modifications.

DESCRIPTION:

Soil caps are designed to reduce soil erosion and inhibit dermal contact with site soil. Also an effective soil cap will reduce infiltration of surface water.

With soil caps, a relatively impermeable material with subsequent resoiling and vegetation is installed. Possible impermeable capping materials include the following:

- o Synthetic membranes
- o Compacted soils
- o Sprayed bituminous membranes
- o Polyurethane foams
- o Soil additives and cements

PERFORMANCE:

Synthetic membranes and compacted soils have been used extensively as capping materials. Considerable experience has been obtained from laboratory and field testing and waste containment applications of synthetic membranes formulated with polyvinyl chloride (PVC), chlorosulfonated polyethylene (HYPALON), polyethylene (PE), high density polyethylene (HDPE), and chlorinated polyethylene (CPE). These materials are chemically compatible with a wide range of organic and inorganic compounds. Permeabilities (to water) are less than 1×10^{-7} cm/sec. Resistance to tearing from settlement is very high because of the membranes' elongation properties and all of the synthetic materials are readily available.

A disadvantage of the synthetic membranes is the limited historical experience on long-term material durability. Present warranties offered by membrane manufacturers are 20 to 30 years, although certain formulations might be stable indefinitely, especially if not exposed to sunlight. Uncertainties over long-term performance of membranes

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must be considered a technical limitation. For this reason, synthetic membranes will be used for capping applications only in combination with other, more reliable materials for long-term application.

Compacted soil caps have been constructed mainly with soils of high clay content, which provide a low permeability and high plasticity. These caps can provide long-term reliability for reducing rainfall percolation into waste; however, clay soil caps are susceptible to degradation by volatile organic compounds.

Capping materials such as polyurethane foams are engineering concepts that have not benefited from wide experience in application. Polyurethane foams have been used in limited cases for daily cover of sanitary landfills. However, their permeability and durability is not equal to conventional synthetic membranes.

Sprayed bituminous membranes such as kerosene cutback asphalt can provide a low-permeability cap at a relatively low cost. These membranes have a lesser tensile strength and puncture resistance than synthetic materials. However, if the subbase and cover of the membrane is adequate, these disadvantages can be minimized. Bituminous-based materials are also resistant to degradation by most inorganic liquids. However, they are more susceptible to deterioration through weathering and environmental action, and are less durable than soil caps.

Cement-based caps are susceptible to cracking from settlement and deterioration. The cost for cement-based caps are equal to or greater than the cost of more appropriate cap construction.

SLURRY TRENCH (In Situ Containment)

MEDIUM:

Contaminated soils or buried waste/residue.

PROCESS TYPE:

Geotechnical

RELATED SITE
EXPERIENCE:

Yes, common practice for restricting groundwater and earth movement.

APPLICABLE
CHEMICALS OF
INTEREST:

All chemicals of interest if suitable barrier materials are used.

TECHNOLOGY
STATUS:

Established Technology with changing modifications

DESCRIPTION:

Slurry trenches are a common form of subsurface barrier because they are relatively inexpensive and are effective in controlling groundwater flows. Slurry trenches are excavated trenches that are backfilled with a mixture of bentonite in soil to form a low permeability zone to control subsurface flows. During construction the trench is held open by the pressure exerted by a bentonite clay slurry; hence the term "slurry trench". As such, the backfilled trench is somewhat plastic and compressible. The mixture of bentonite and soil can yield permeabilities in the treated soils to as low as 1×10^{-8} cm/sec.

Slurry trenches can be excavated to depths of 200 feet but common practice for trenches are up to 60 feet deep. Practical widths of the trenches are required to accommodate the excavating equipment and a minimum width of about 24 inches is common.

Solidifying of slurry trenches can be accomplished by backfilling with a mixture of bentonite and the excavated material or the slurry can be allowed to solidify on its own by incorporating cement to the original slurry. Due to the changes in density and losses through seepage during excavation, it is important to recirculate the slurry to maintain its integrity. Control of the slurry is maintained by recirculating on a continuous basis through a central mixing unit where additional bentonite can be added to increase density or excavated material may possibly be removed.

It is an important aspect of slurry trench construction to tie the trench into an underlying impervious zone so as to effectively cut off the flow of groundwater or contaminants.

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SLURRY TRENCH
(In Situ Containment)

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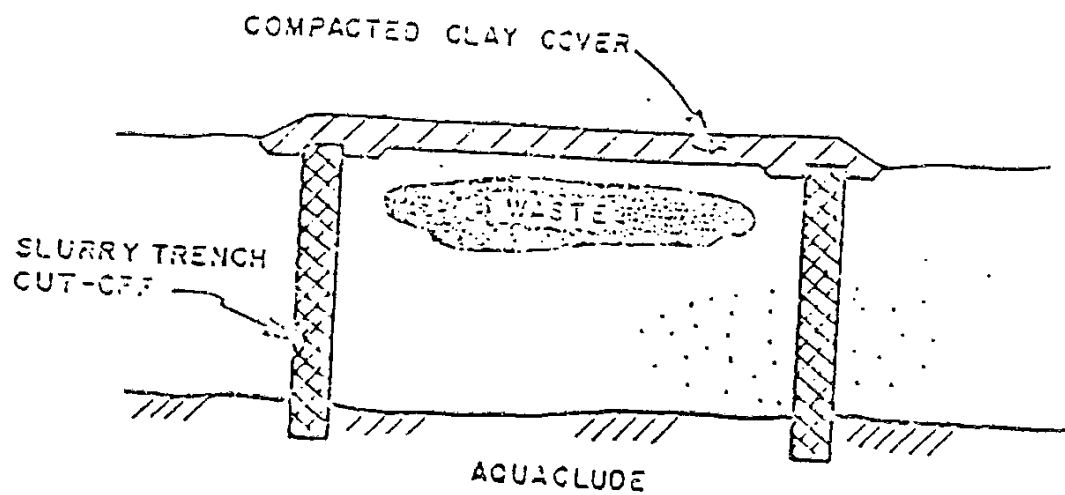
PERFORMANCE:

Conditions suitable for a slurry trench include soils containing fines, presence of a confining layer at moderate depths, absence of obstacles to excavation such as boulders, foundations, abandoned utilities, moderate groundwater gradients and absence of coarse high flow zones. Coarse grained soils might pose a problem to slurry trench construction and their presence must be evaluated. Obstacles to construction such as boulders and underground utilities need to be ascertained.

Another important consideration is the chemical compatibility of the slurry trench with subsurface contaminants and the potential of degradation of the slurry trench. The presence of strong acids or bases, strong salt solutions and some organic compounds might have a deleterious effect on the slurry trench construction and performance. Testing should be carried out as to the compatibility of the slurry formula with suspected contaminants.

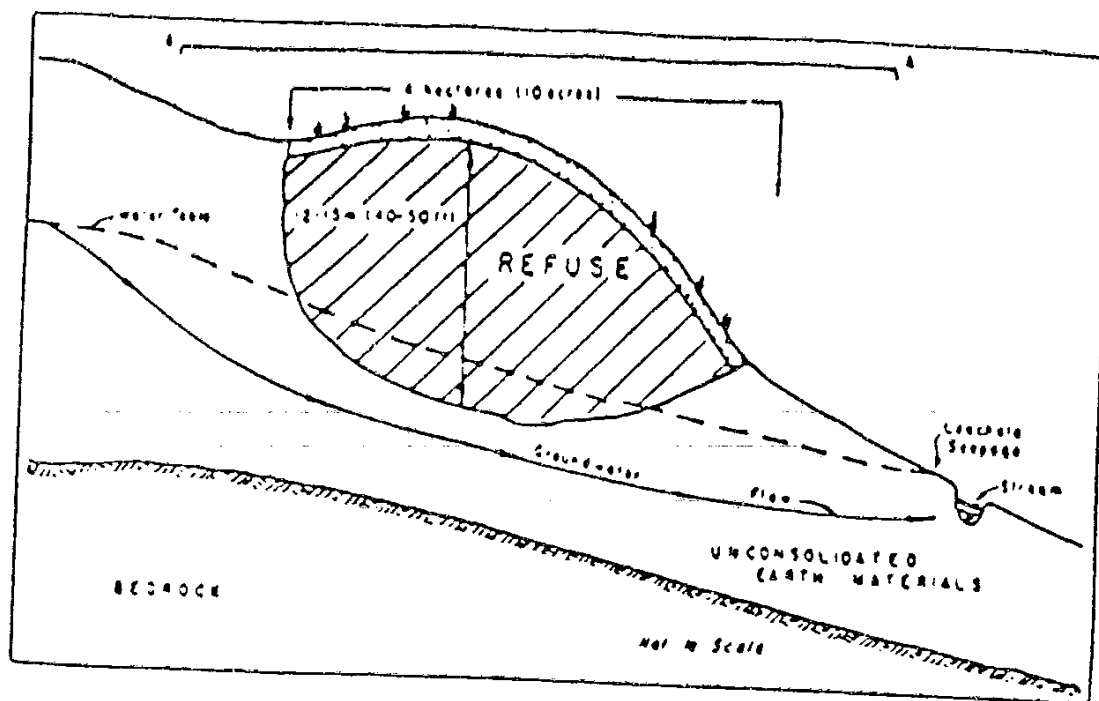
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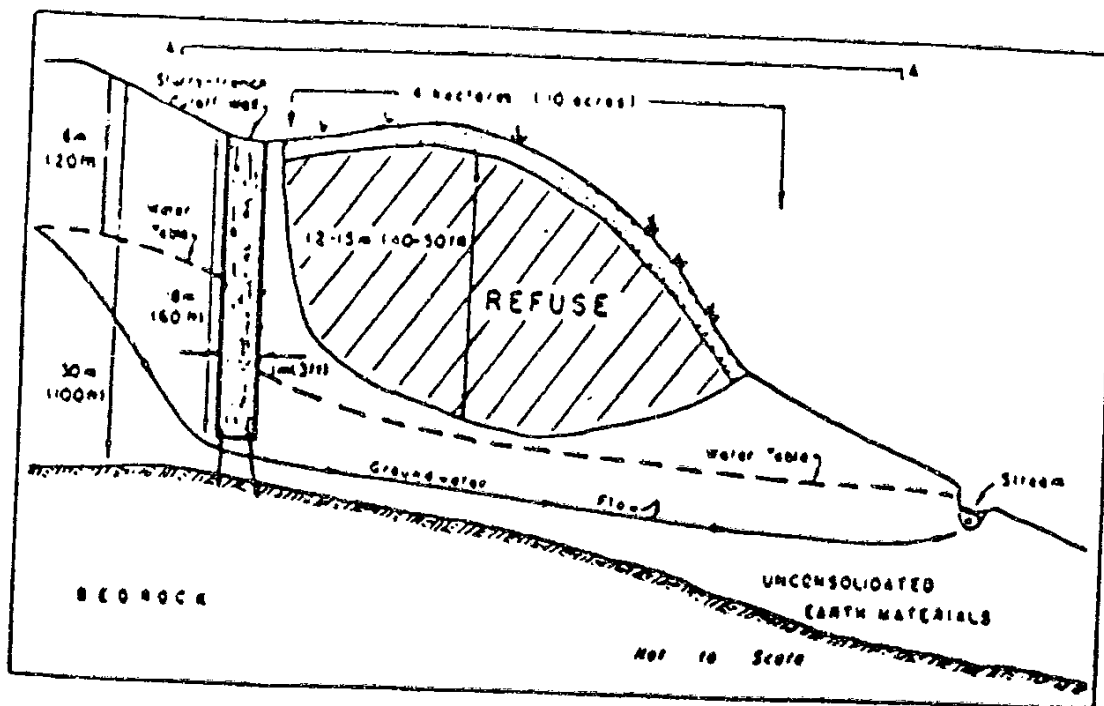


Isolation of existing buried waste (Ryan, 1980).

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(a)



(b)

Cross section of landfill (a) before and (b) after slurry-trench cutoff wall installation (Tolman et al., 1978).

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GROUT CURTAIN (In Situ Containment)

MEDIUM:

Porous soils and fractured rock treated in place

PROCESS TYPE:

Geotechnical

RELATED SITE EXPERIENCE:

Yes(limited)

APPLICABLE CHEMICALS OF INTEREST:

All chemicals of interest if suitable barrier materials are used.

TECHNOLOGY STATUS:

Established technology with changing modifications.

DESCRIPTION:

Grouting is a process of injecting under pressure suitable mixtures of cement and water or other admixtures into the ground for the purpose of creating a seepage barrier. The grout mixture is injected through holes drilled from the ground surface specifically for this purpose from the ground surface. Generally they are drilled from the vertical but angle holes may be employed depending on site conditions or project requirements. A grout curtain is formed by controlling the horizontal and vertical placement of the grout to form a contiguous zone of cemented impermeable soils. Grout mixtures available include cement, clay (bentonite), silicates (chemical) and organic polymers (chemical).

PERFORMANCE:

The effectiveness of grouting is contingent upon several factors. First is the composition of the grout itself which is a function of several variables. These variables include soil type to be injected into, pollutant to be inhibited, time since pollutant started and time for installation. Chemical Grouts (generally silicate) are effective in fine-grained soils but are not suitable for highly acidic or alkaline environments because their gel formation is a acid-base reaction. A particulate cement/bentonite grout is used with coarse grained soils.

There are many admixtures which can be used with cement grout to alter its properties to best suit site conditions. These properties include altering setting times, reducing shrinkage, increase plasticity or lower strength of grout. A second factor is the pressure of injection. Excessive pressure can weaken the strata by fissuring rock or by opening existing fissures in closely jointed rock. Pressure must be maintained at such a level to obtain penetration

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and keep grouting time to a minimum. A grout curtain would be most effective in stopping the flow of pollutants rather than groundwater itself as a rapid groundwater flow would dilute the grout mixture so as to reduce its efficiency. Grouting success is very dependent on site conditions so a thorough investigation and understanding of the site is needed.

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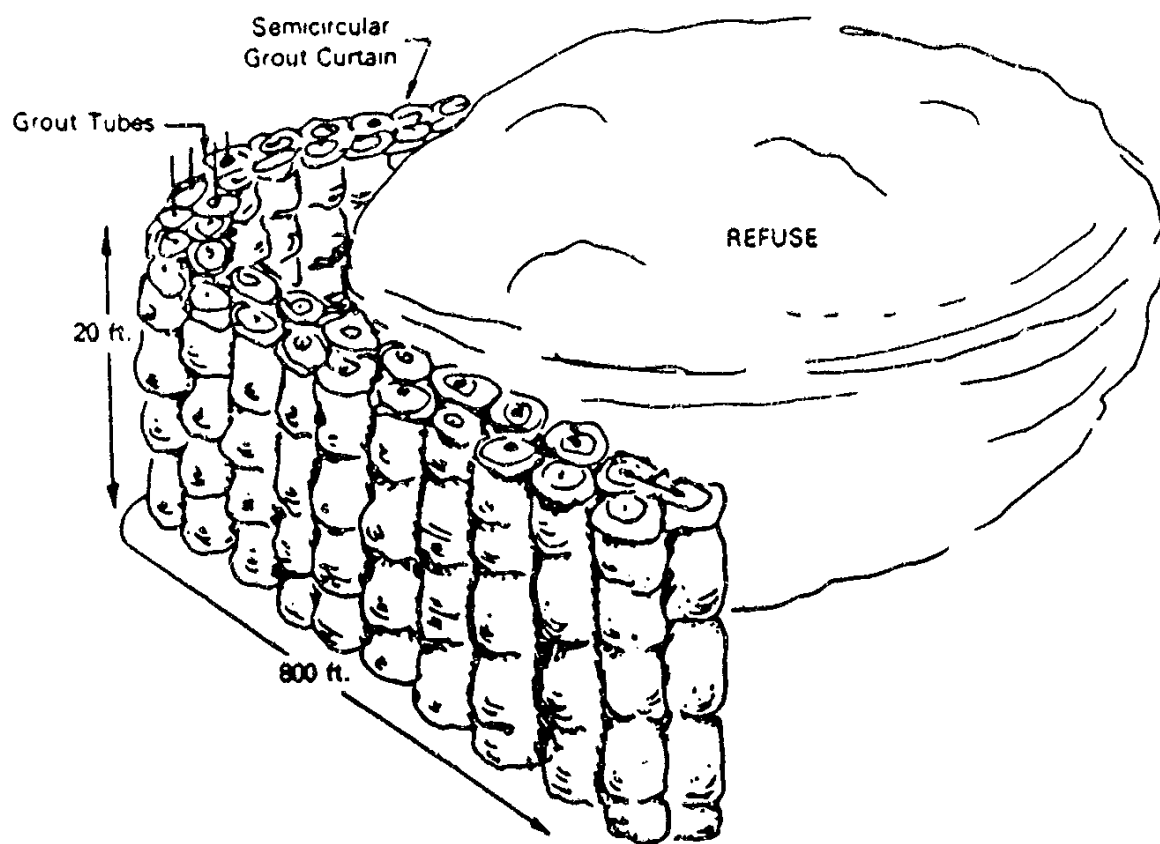
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Grout Curtain
(In Situ Containment)

SEMICIRCULAR GROUT CURTAIN AROUND UPGRADIENT END OF LANDFILL

(Source: EPA, 1978)

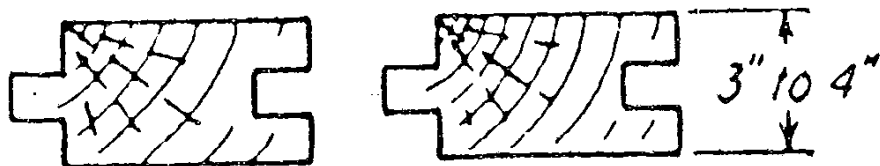


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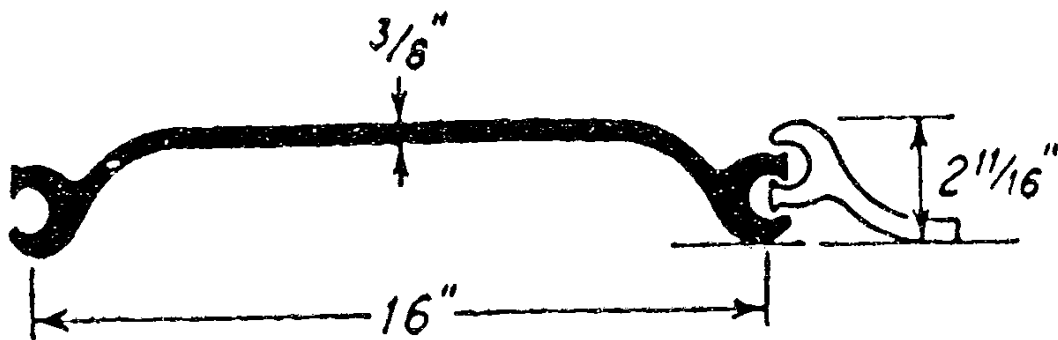
SHEET PILES
(In Situ Containment)

<u>MEDIUM:</u>	Contaminated soil or buried wastes/residues
<u>PROCESS TYPE:</u>	Geotechnical
<u>RELATED SITE EXPERIENCE:</u>	Yes (limited)
<u>APPLICABLE CHEMICALS OF INTEREST:</u>	All chemicals of interest if suitable barrier materials are used
<u>TECHNOLOGY STATUS:</u>	Established Technology with changing modifications
<u>DESCRIPTION:</u>	Sheet piles create a physical barrier to groundwater movement through the placement of steel, pre-cast concrete or treated wood materials into the ground. Sheet piles are installed by driving steel interlocking sections individually with a pile hammer. Pile hammer types include drop, single-action steam, double-action steam, diesel, vibratory and hydraulic. Piles are driven to the desired depth based on design criteria established from subsurface investigations. When first installed, sheet piles are not totally impermeable but over time fines carried by groundwater fill the small gaps between sheets, making the structure relatively impermeable.
<u>PERFORMANCE:</u>	Construction of a sheet pile structure is not difficult and the equipment and materials required are readily available. However, certain chemicals can attack steel and a protective coating may be required to extend its service life. No maintenance is required following construction. The effectiveness of the sheet piling is dependent upon the soils present. Soil containing cobbles and/or construction debris can interfere with the driving of steel sheeting piles. In soils containing large rocks or debris, the interlocks may separate and an ineffective barrier to groundwater flow will result. Sheet piling is used primarily for temporary de-watering of construction or as erosion protection where some other barrier, such as a slurry wall, intersects flowing surface water. Concrete is used primarily where great strength is required. Wood, although less expensive is an ineffective long-term water barrier.

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(a)



(b)

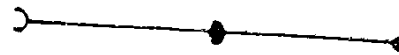
Sheet piling: (a) timber, (b)
steel (section MP 112, U.S. Steel Co.).

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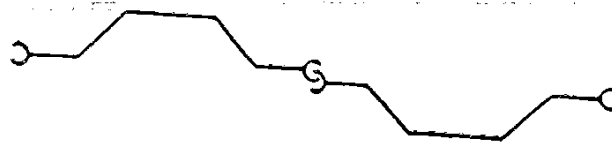
SOME STEEL PILING SHAPES AND INTERLOCKS

(Source: Veguhardt, 1962)

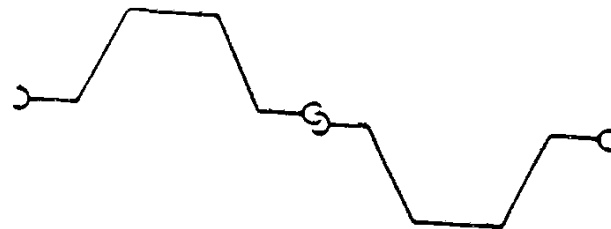
Straight Web Type



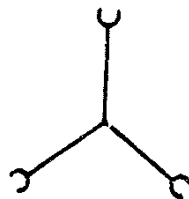
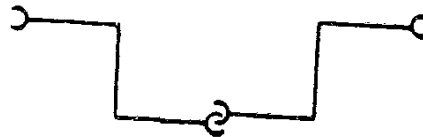
Arch Web Type



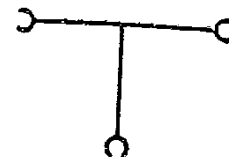
Deep Arch Web Type



Z-Type



Y-Fitting



T-Fitting

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2.0 REMOVAL TECHNOLOGIES

2.1 GROUNDWATER COLLECTION

PUMPING WELLS

INTERCEPTOR TRENCHES AND SUBSURFACE DRAINS

2.2 SOIL/RESIDUE REMOVAL

EXCAVATION

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2.1 GROUNDWATER REMOVAL
PUMPING WELLS
INTERCEPTOR TRENCHES & SUBSURFACE DRAINS

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PUMPING WELLS
(Groundwater Removal)

MEDIUM:

Contaminated groundwater and associated fluid oils

PROCESS TYPE:

Physical removal

RELATED SITE EXPERIENCE:

Yes, common practice for removing contaminated groundwater and associated oils from the subsurface environment and in preventing groundwater from intercepting a contaminated zone

APPLICABLE CHEMICALS OF INTEREST:

All soluble organics and inorganics in the water phase along with those organics associated with any fluid oils present. At representative groundwater temperatures, tars are not fluid enough to be removed by pumping wells.

TECHNOLOGY STATUS:

Established Technology with changing modifications

DESCRIPTION:

There are several applications of groundwater pumping to control contaminated groundwater at a plant or disposal site. Three primary applications are:

- 1) Pumping to lower a water table
- 2) Pumping to contain a plume
- 3) Groundwater treatment systems

Lowering of the water table can be implemented to prevent stream discharge of contaminated water, eliminate contact with a disposal site and prevent contamination of an underlying aquifer. Well point dewatering systems or the use of deep wells are methods most commonly employed for lowering the water table. A well point dewatering system consists of a group of closely spaced wells, usually connected to a central pump for the entire system. A deep well system has fewer wells but of larger capacity, each with its own pump and connected to a single header pipe for removal.

Plume containment is accomplished by 1) using a series of extraction and injection wells that will allow water within the plume to be pumped, treated and pumped back into the aquifer, 2) low pumping rates to contain a plume with no subsequent recharge to the aquifer or 3) pumping and treatment of the plume followed by recharge using recharge basins. Plume containment by pumping is an effective means of preventing the eventual contamination of drinking water wells or the pollution of streams or confined aquifers that are hydraulically connected to the contaminated

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PUMPING WELLS
(Groundwater Removal)

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groundwater. Pumping without subsequent recharge may be acceptable where small quantities are involved, but for large groundwater flows or when residents depend on the groundwater for drinking water source, recharge will be necessary. With the extraction/injection well technique, consideration must be taken in design so that the radii of influence do not overlap.

Containing a plume by extraction only is feasible if groundwater withdrawal is low and the aquifer is not used as a drinking source. Groundwater pumping with recharge through seepage basins is similar to the extraction/injection technique except that recharge is accomplished by natural means and not artificial pressures. This type of recharge method is applicable if the aquifer is not used as a drinking source so as not to interfere with public use.

Groundwater pumping systems can be coupled with groundwater treatment systems for specific groundwater contamination problems. Treatment systems should be used in conjunction with pumping to lower a water table or to contain a plume.

PERFORMANCE:

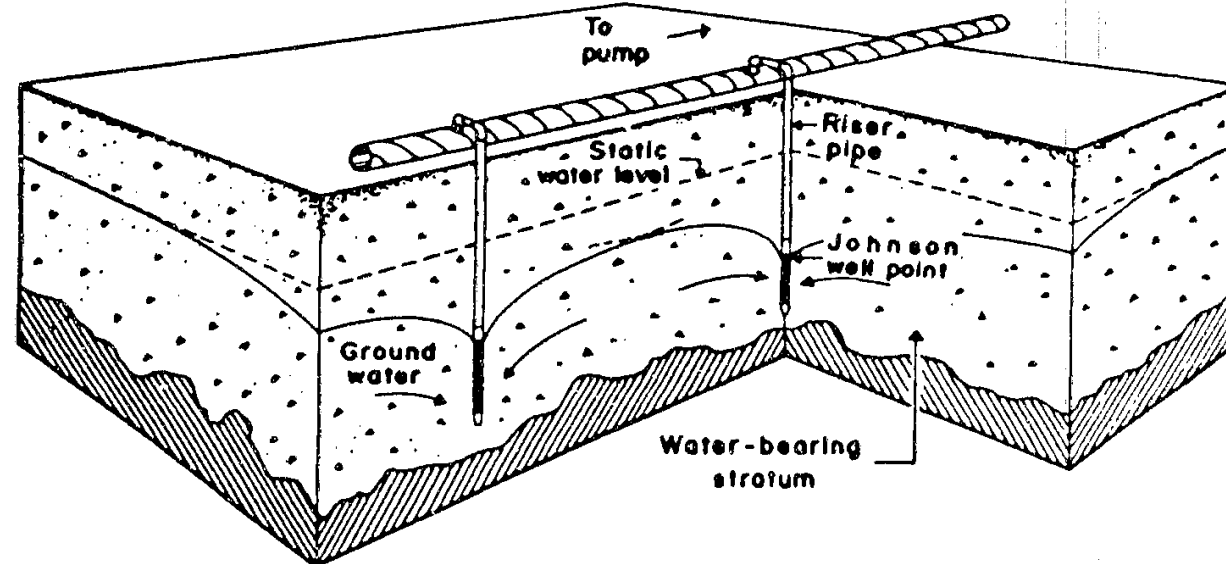
Each type of technique or application has its own merits and site conditions would dictate which is best suited.

Pumping wells are a long standing method of remedial action for groundwater. Techniques are well tested both in the lab and field. There is frequently, however, larger costs involved in the implementation, maintenance and operating costs over a long period of time for this type of method over others. A thorough investigation and analysis of site conditions is required to best evaluate pumping wells as a final solution.

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SCHEMATIC OF A WELL POINT DEWATERING SYSTEM

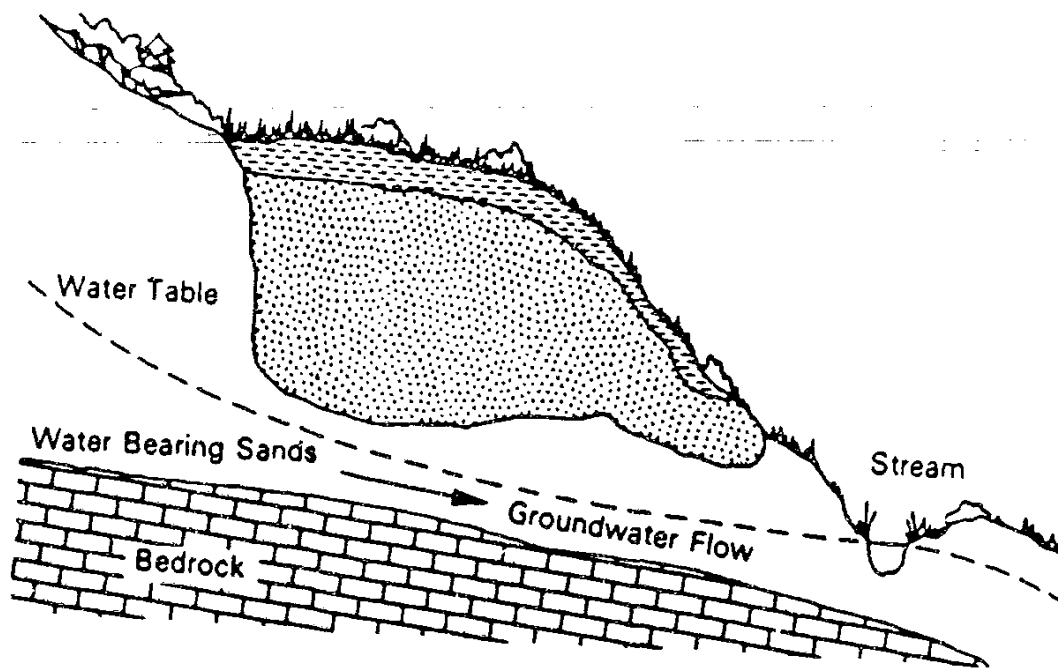
(Source: Johnson, 1975)



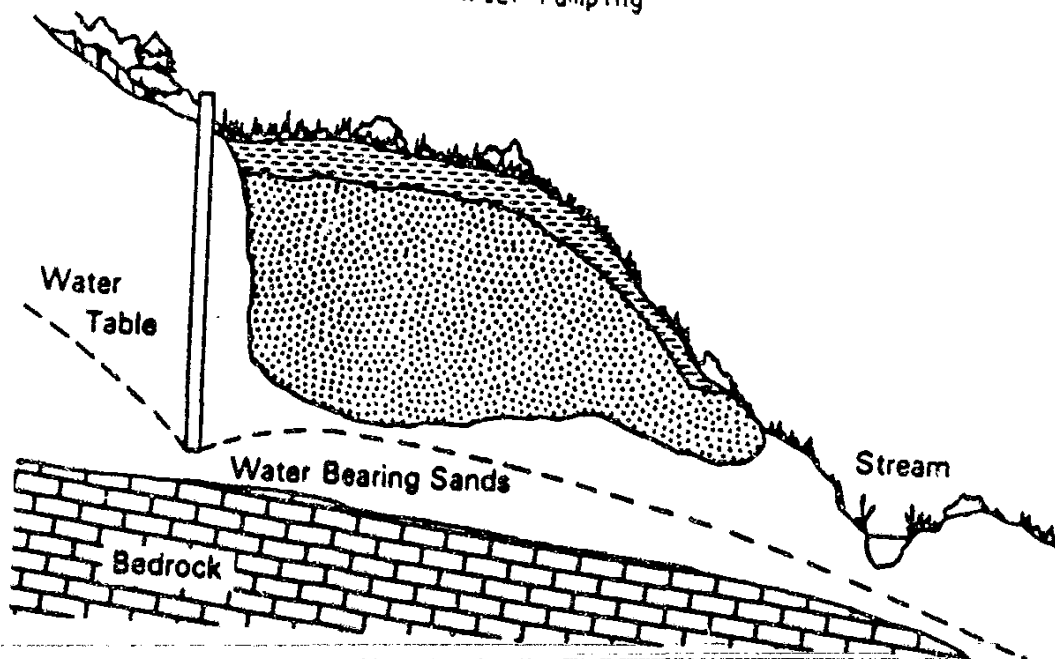
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LOWERING A WATER TABLE TO PREVENT STREAM DISCHARGE OF CONTAMINATED WATER

Before Pumping



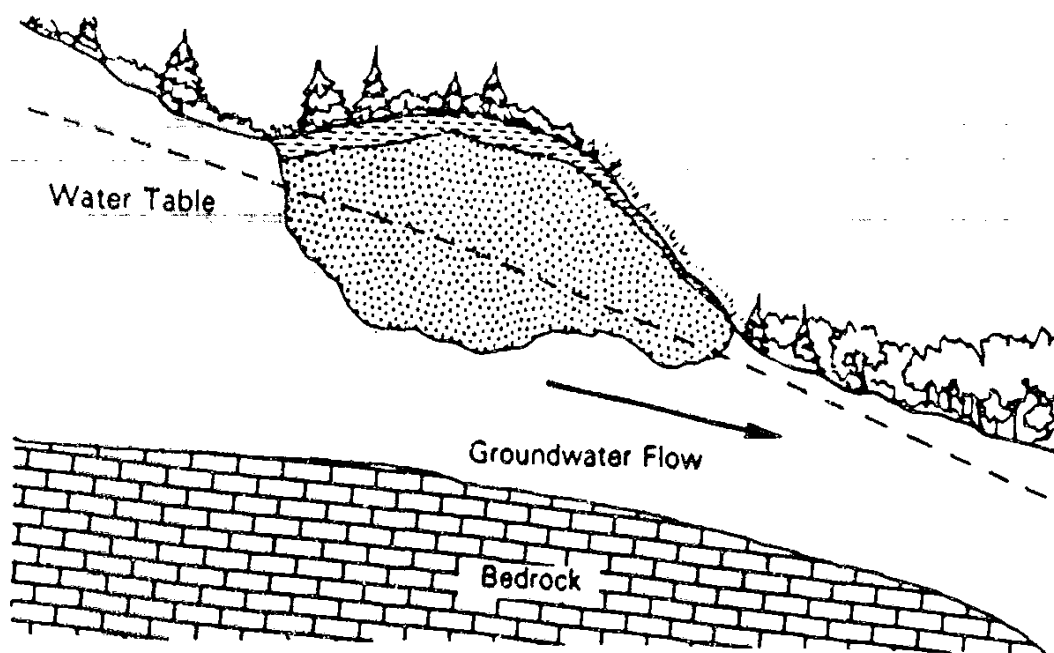
After Pumping



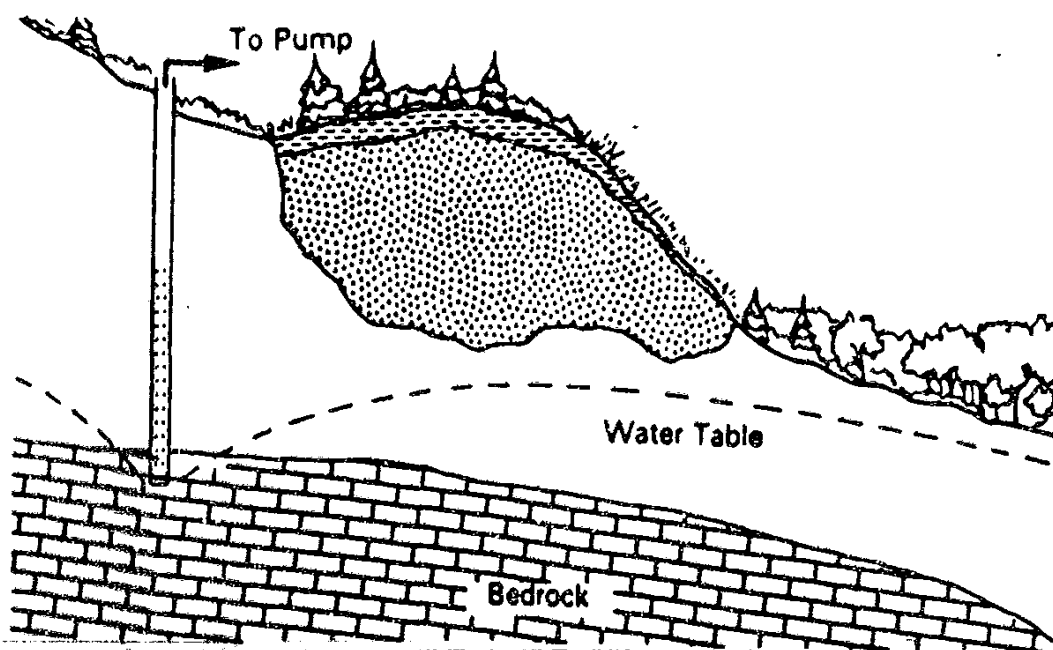
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LOWERING THE WATER TABLE TO ELIMINATE CONTACT WITH A DISPOSAL SITE

Before Pumping



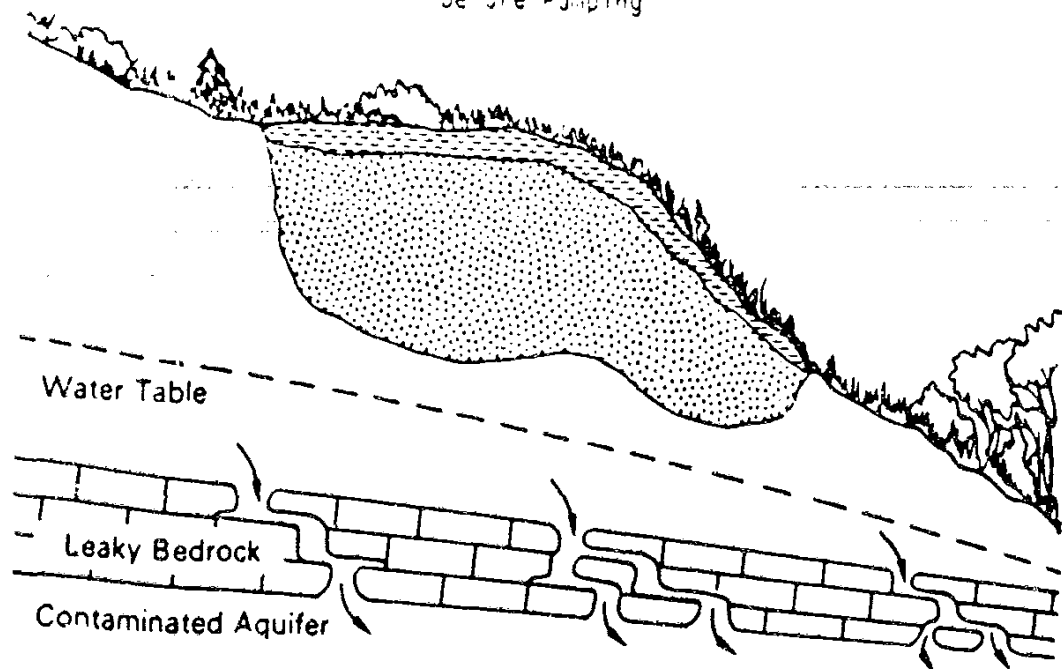
After Pumping



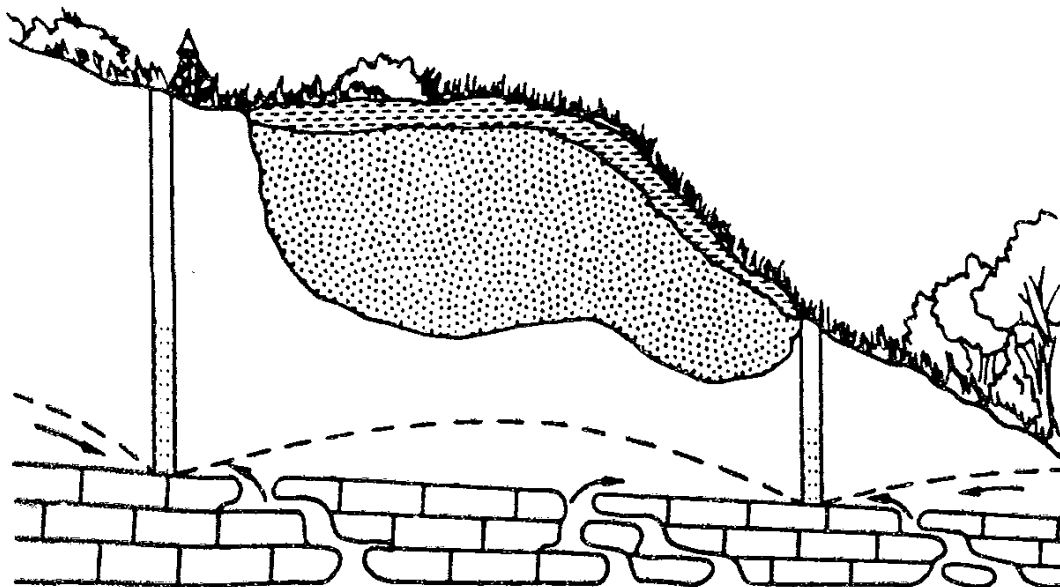
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LOWERING WATER TABLE TO PREVENT CONTAMINATION OF AN UNDERLYING AQUIFER

Before Pumping



After Pumping



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INTERCEPTOR TRENCHES AND SUBSURFACE DRAINS (Groundwater Removal)

<u>MEDIUM:</u>	Contaminated Groundwater and associated fluid oils
<u>PROCESS TYPE:</u>	Physical Removal
<u>RELATED SITE EXPERIENCE:</u>	Yes, common practice for intercepting and removing contaminated groundwater and associated oils from the subsurface environment.
<u>APPLICABLE CHEMICALS OF INTEREST:</u>	All soluble organics and inorganics in the water phase along with those organics associated with the fluid oils present. At representative groundwater temperatures, tars are not fluid enough to be removed by pumping wells.
<u>TECHNOLOGY STATUS:</u>	Established Technology with changing modifications.
<u>DESCRIPTION:</u>	<p>Interceptor systems involve the excavation of a trench below the water table (Interceptor Trenches) and possibly the placement of a pipe within the trench (Subsurface Drains). Construction is relatively simple and involves excavation of the trench, placing perforated pipe (if so designed) and backfilling with coarse material such as gravel. Interceptor trenches can be either active (pumped) or passive (gravity flow). Active systems require continual pumping to get water down to the bottom of the trench. This is accomplished by the placement of vertical removal wells or a perforated collector pipe in the bottom of the trench. Passive systems are usually left open with the installation of a skimming pump for removal of the pollutant only. All interceptor trenches require an excavation of at least 3 to 4 feet below the water table to prevent the escape of inflowing pollutants.</p> <p>Subsurface drains involve the use of trenches with perforated pipe installed. A collector system for drains include lateral drains flowing into a main collector pipe (Header) with gravity flow to a sump for pumping. Two types of drain systems are relief and interceptor drains. Relief drains are used in areas of relatively flat hydraulic gradients. They are generally used to lower the water table beneath a site or prevent contamination from reaching a deeper, underlying aquifer. Relief drains are installed in parallel on either side of a site so that there is an overlap of areas of influence and contaminated</p>

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1 INTERCEPTOR TRENCHES AND
SUBSURFACE DRAINS
(Groundwater Removal)

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groundwater does not flow between the drain lines. Interceptor drains are used to collect groundwater from an up gradient source in order to prevent leachate from reaching wells or surface water located hydraulically downgradient from the site. Installation is perpendicular to groundwater flow.

PERFORMANCE:

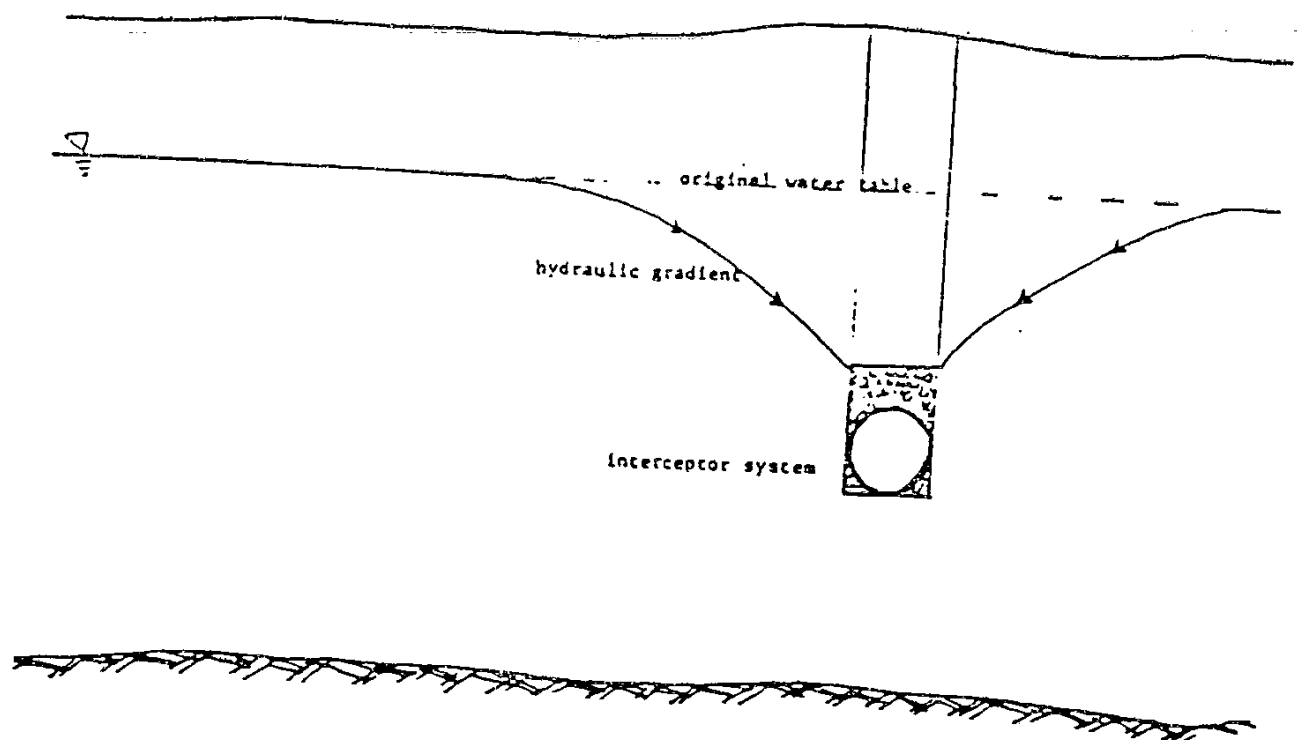
Both trenches and drains have relatively low construction and operating costs, but the use of drains requires continuous and careful monitoring to assure adequate leachate collection and are not well suited to poorly permeable soils. Trenches on the other hand require extensive maintenance for operating efficiency and may require additional safety/security measures due to the open structure.

Since trenches and drains essentially function like an infinite line of extraction wells, they can perform many of the same functions as wells. For shallow contamination problems, trenches and drains can be more cost effective than pumping wells, particularly in strata with low or variable hydraulic conductivity. Under these conditions, it would be difficult to design and it would be cost prohibitive to operate a pumping system to maintain a continuous hydraulic boundary. Interceptor trenches and subsurface drains may also be preferred over pumping where groundwater removal is required over a period of several years, because the operation and maintenance costs associated with pumping are substantially higher. One of the biggest drawbacks to the use of trenches and drains is that they are generally limited to shallow depths. Although it is technically feasible to excavate a trench to almost any depth, the costs of shoring, dewatering and hard rock excavation can make trenches and drains cost prohibitive at depths of more than 40 feet. However, in stable low permeability soils where little or no rock excavation is required, they may be cost effective to depths of 100 feet. Also, it is more difficult to remove oils from the subsurface via drains. The use of interceptor systems produce less fluid to be handled than pumping systems.

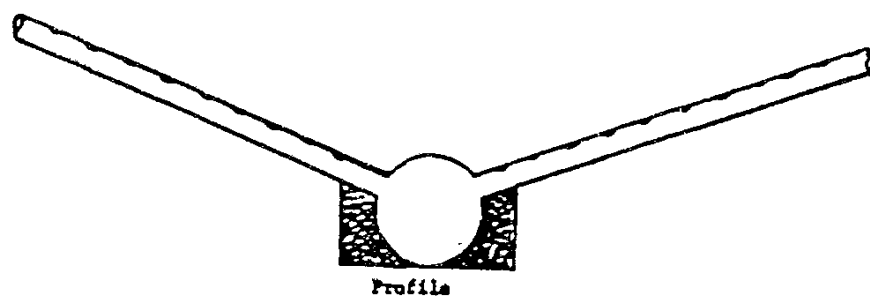
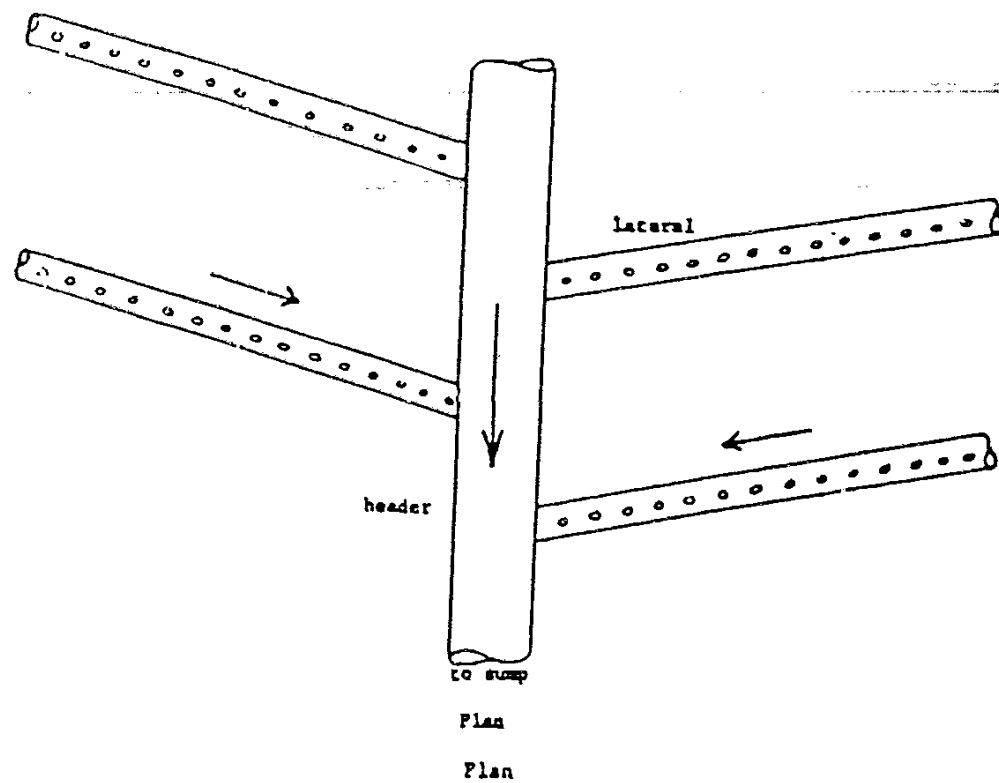
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2 INTERCEPTOR TRENCHES AND
SUBSURFACE DRAINS
(Groundwater Removal)

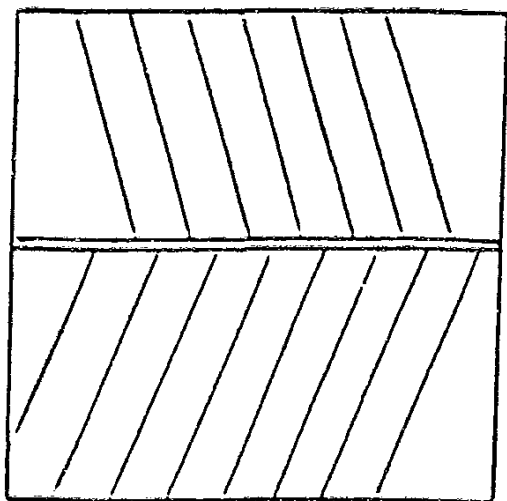


Hydraulic gradient toward interceptor system.

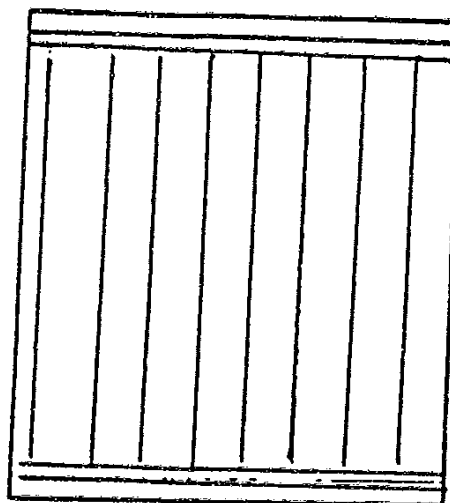


Collector drain system.

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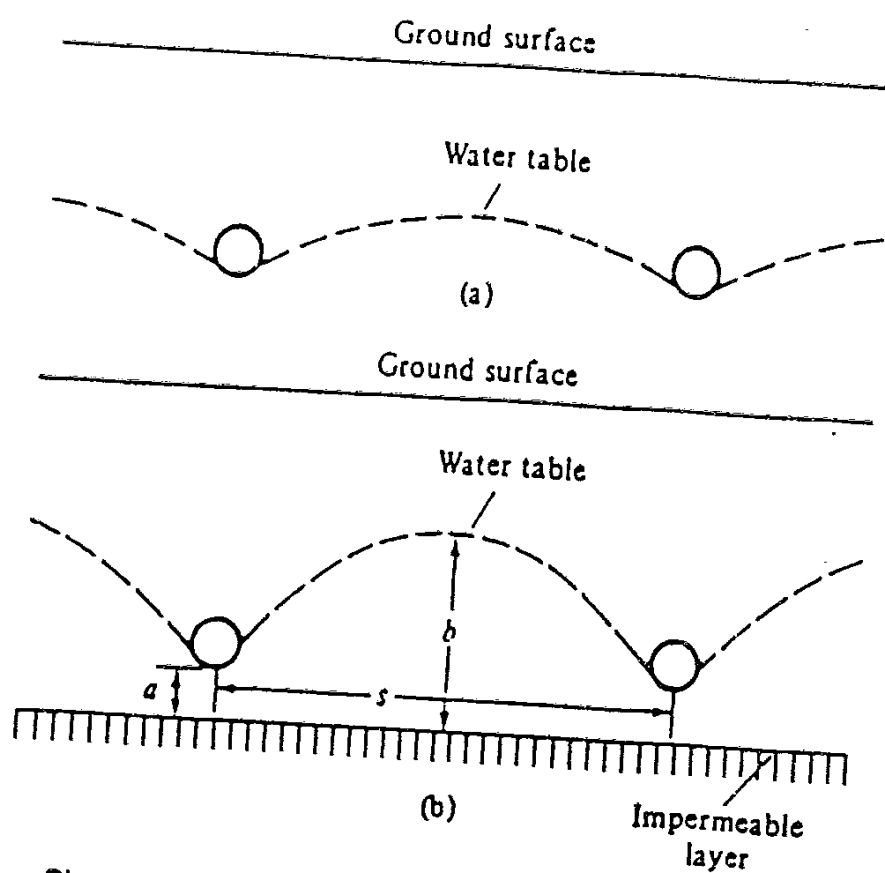
(a) Herringbone



(b) Gridiron

Collector system layouts.

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Shape of water table adjacent to tile drains: (a) relatively permeable soil; (b) less permeable soil (Spangler and Handy, 1973).

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2.2 SOIL RESIDUE REMOVAL
EXCAVATION - TANKS AND LAGOONS

008200

EXCAVATION - TANKS AND LAGOONS (Soil/Residue Removal)

MEDIUM:

Contaminated soils, waste piles and sludges.

PROCESS TYPE:

Physical removal.

RELATED SITE EXPERIENCE:

Yes, common practice for removal of contaminated solid/semi-solid material.

APPLICABLE CHEMICALS OF INTEREST:

All organic and inorganic contaminants which have the potential chemicals to leach off solid material. Also those solid chemicals which pose an unacceptable risk.

TECHNOLOGY STATUS:

Established technology with changing modifications

DESCRIPTION:

Excavation of contaminated soils/residues or subsurface wastes may be performed for one or more of the following reasons:

- o Short term protection of public health and environment through the elimination of contaminant sources.
- o Reduction or elimination of long term liability from adverse public health and/or environmental effects, if contaminant transport is possible.
- o Compliance with federal or state mandated restoration plans.
- o Property restoration for redevelopment.

Technical factors affecting excavation include site location and current use; site topography, hydrology and geology; vertical and horizontal extent of contamination; contaminant distribution; planned disposition of excavated material; and site restoration needs (e.g. clean up levels).

Sludges contained in tanks may have to be removed by digging or excavation. Some sludges with more hazardous characteristics may require special considerations based on the classification of these materials as RCRA hazardous wastes.

During the selection of removal methods, accessibility plays an important role. Mechanized equipment could lower costs if they have access to the contaminated area. Shovels and

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Excavation - Tanks and Lagoons
(Soil/Residue Removal)

008201

front end loaders would be the most appropriate equipment in many instances for soil/residue removal.

PERFORMANCE:

Conventional soil excavation methods are applicable to most sites and the selection of types of equipment and techniques will depend to a large extent on the depth of contamination, soil type, total volume and schedule for removal.

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**Excavation - Tanks and Lagoons
(Soil/Residue-Removal)**

3.0 TREATMENT TECHNOLOGIES

3.1 IN SITU TREATMENT

SUBSURFACE BIORECLAMATION

SURFACE BIORECLAMATION

SOIL FLUSHING

CHEMICAL TREATMENT FIXATION

AIR/STEAM STRIPPING

3.2 ON-SITE WATER TREATMENT

ACTIVATED SLUDGE

AERATION TANK

FIXED BED

BIOFLOWSM

SEQUENCING BATCH REACTOR

TRICKLING FILTER

STEAM STRIPPING

BIOFILTRATIONSM

CARBON ADSORPTION

CHEMICAL OXIDATION

DISSOLVED AIR FLOTATION

EVAPORATION

FILTRATION

PHYSICAL CHEMICAL SEPARATION

ION EXCHANGE

NEUTRALIZATION

UV CHEMICAL OXIDATION

PHOTOLYSIS

REVERSE OSMOSIS

008203

SOLVENT EXTRACTION

WET AIR OXIDATION

3.3 ON-SITE SOIL/RESIDUE TREATMENT

COMPOSTING

ENGINEERED BIODEGRADATION SYSTEMSM (EBDSSM)

INCINERATION

AIR STRIPPING (SEE SECTION 3.2)

STEAM STRIPPING (SEE SECTION 3.2)

SOIL WASHING

SONIC TREATMENT

STABILIZATION

THERMAL DESORPTION

3.4 OFF-SITE SOIL/RESIDUE TREATMENT

INCINERATION (SEE SECTION 3.3)

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3.1 IN SITU TREATMENT

SUBSURFACE BIORECLAMATION

SURFACE BIORECLAMATION

SOIL FLUSHING

CHEMICAL TREATMENT FIXATION

AIR/STEAM STRIPPING

008205

SUBSURFACE BIORECLAMATION (In Situ Treatment)

MEDIUM:

Subsurface soils/groundwaters.

PROCESS TYPE:

Biological (aerobic or anaerobic) oxidation and adsorption/desorption.

RELATED SITE EXPERIENCE:

Petroleum industry, wood treating sites, coking and coal tar distillation sites, and manufactured gas plant sites, chemical plants and other industries. Generally applied to restoration of soils contaminated by leaky underground storage tanks.

APPLICABLE CHEMICALS OF INTEREST:

Conventional pollutants, phenolics, polynuclear aromatic hydrocarbons (PAH), volatile organics, polychlorinated biphenyls (PCB), and biodegradable inorganics.

TECHNOLOGY STATUS:

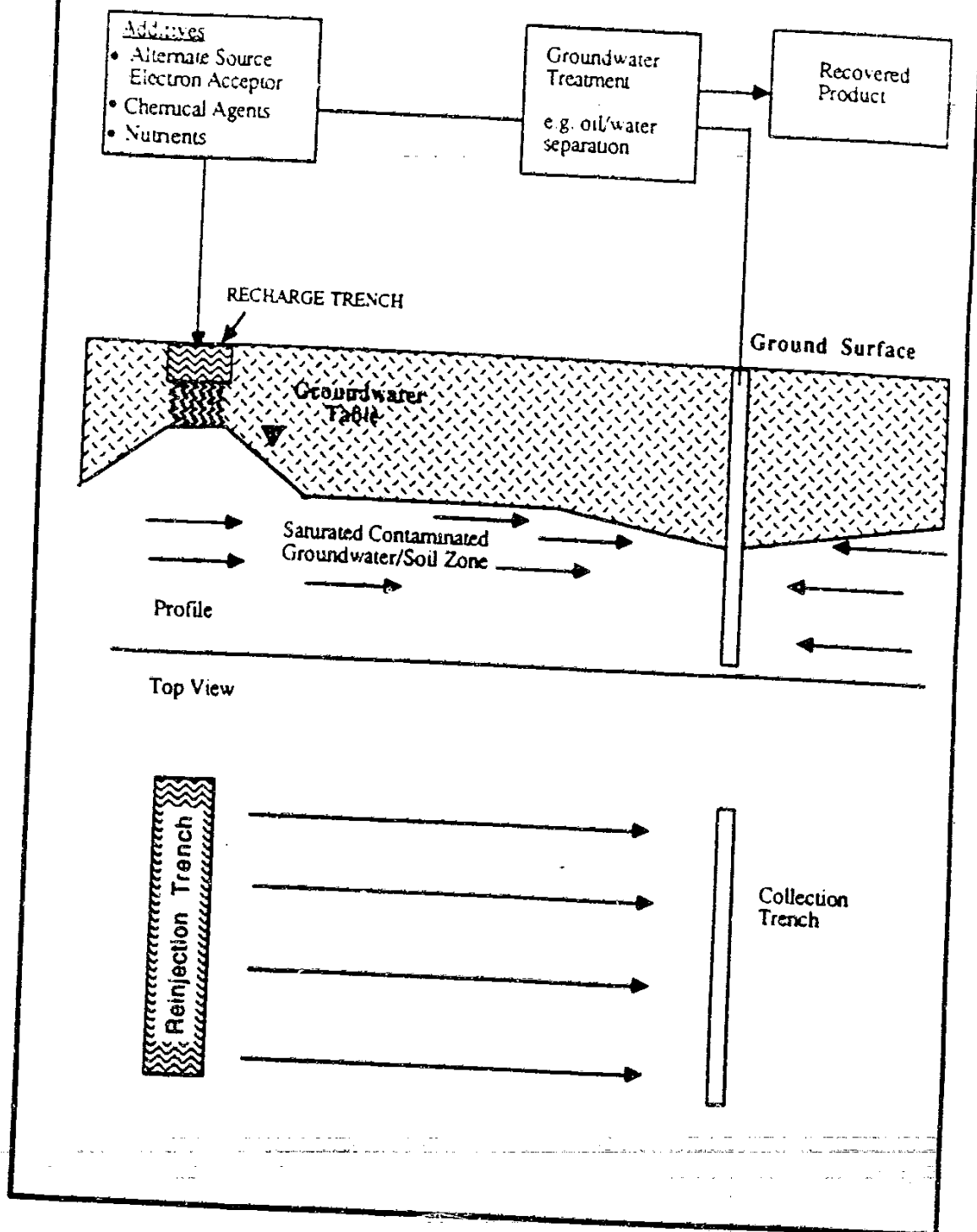
Bench-scale, pilot-scale, full-scale. Engineering technology with increasing full-scale applications to a wide range of site restoration issues.

DESCRIPTION:

In situ Subsurface BioReclamation is a proven method for restoration of soils and groundwaters contaminated with biodegradable organics and inorganics. It is a process whereby groundwater, containing sufficient additives, is recirculated through a contaminated subsurface soil/groundwater zone in such a manner so as to promote the growth of indigenous microorganisms for subsequent biodegradation of contaminants. As illustrated in Figure 1, the process involves the addition of nutrients and an electron acceptor source, e.g. oxygen to stimulate the growth of naturally occurring bacteria to utilize the organics both as an energy source and a food source. Both aerobic and anaerobic conditions apply. Surfactants may also be added to aid in the desorption of chemical contaminants from soil particles into the water phase with biodegradation then occurring. The recirculated groundwater is usually introduced into the subsurface via injection wells or a french drain system. Extraction wells or trenches recover the displaced and treated groundwater. Figure 1 depicts a trench system. The extracted treated groundwater may be further treated in above ground treatment processes and then discharged or reinjected back into the ground providing a cyclic flushing action of the subsurface contaminated soils. Such above ground treatment may only involve only oil/water separation or also be designed for

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FIGURE 1
IN SITU SUBSURFACE BIORECLAMATION TREATMENT PROCESS SCHEMATIC



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reduction of soluble chemicals. The main objective of such a process is to enhance biological activity in situ to the degree that biodegradation of soil contaminants is enhanced beyond the degree to which contaminant reduction would occur with just soil flushing alone.

PERFORMANCE:

Numerous bench-scale, pilot-scale and full-scale use of in situ Subsurface BioReclamation treatment has been demonstrated. To date, most full-scale applications have focused on restoration of soils and groundwaters contaminated by soluble hydrocarbons from leaky underground storage tanks, e.g. volatile organics. Keystone Environmental Resources, Inc. is presently involved in both laboratory bench-scale and full-scale in situ Subsurface BioReclamation treatment of soils and groundwaters contaminated with phenolics including pentachlorophenol, polynuclear aromatic hydrocarbons, and volatile aromatics. Bench-scale work demonstrated pentachlorophenol reduction from an initial soil concentration of approximately 13,000 mg/kg (dry weight) to approximately 1,000 mg/kg in an eight week period where in situ subsurface bioreclamation was simulated.

In situ Subsurface BioReclamation, possibly used in conjunction with soil extraction to remove bulk interstitial organics, could be employed where significant volumes of soil are contaminated and where the soil and hydrogeological situation is appropriate. The technique may prove especially valuable to deal with subsurface contamination around existing structures where excavation is impractical.

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SURFACE BIORECLAMATION (In Situ Treatment)

MEDIUM:

Surface soils.

PROCESS TYPE:

Biological aerobic oxidation, volatilization, adsorption/desorption and photolysis.

RELATED SITE EXPERIENCE:

Petroleum industry, wood treating sites, coking and coal tar distillation sites, manufactured gas plant sites, chemical plants and other industries.

APPLICABLE CHEMICALS OF INTEREST:

Conventional pollutants, phenolics, polynuclear aromatic hydrocarbons (PAH), volatile organics, polychlorinated biphenyls (PCB), and biodegradable inorganics.

TECHNOLOGY STATUS:

Bench-scale, pilot-scale, full-scale. Established technology with increasing regulatory control.

DESCRIPTION:

In situ Surface BioReclamation refers to the treatment of surface contaminated soils to biodegrade and immobilize chemical contaminants of interest. The upper 0.5 to 1.5 feet of the surface is managed to promote the growth of indigenous aerobic microorganisms to biodegrade contaminants and to promote immobilization of contaminants. In this system, contaminated surface soil, such as that resulting from a spill, is treated in place.

Figure 1 schematically depicts those factors which must be considered to properly manage an in situ Surface BioReclamation treatment process. As given treatment generally consists of optimizing conditions of pH, temperature, soil moisture content soil oxygen content, and nutrient concentration to stimulate the growth of microorganisms that will feed on the chemical contaminants present. Attention must also be given to evaporation, contaminant volatilization, control of precipitation run-on and run-off, and other amendment addition. The soil must also be periodically tilled which aids in aerating the soil and exposing new soil surfaces to biodegradation. Transport of contaminants into the subsurface via percolation of water must also be addressed.

Biodegradation of chemical contaminants occurs through the interrelated processes of chemical desorption, solubilization and subsequent

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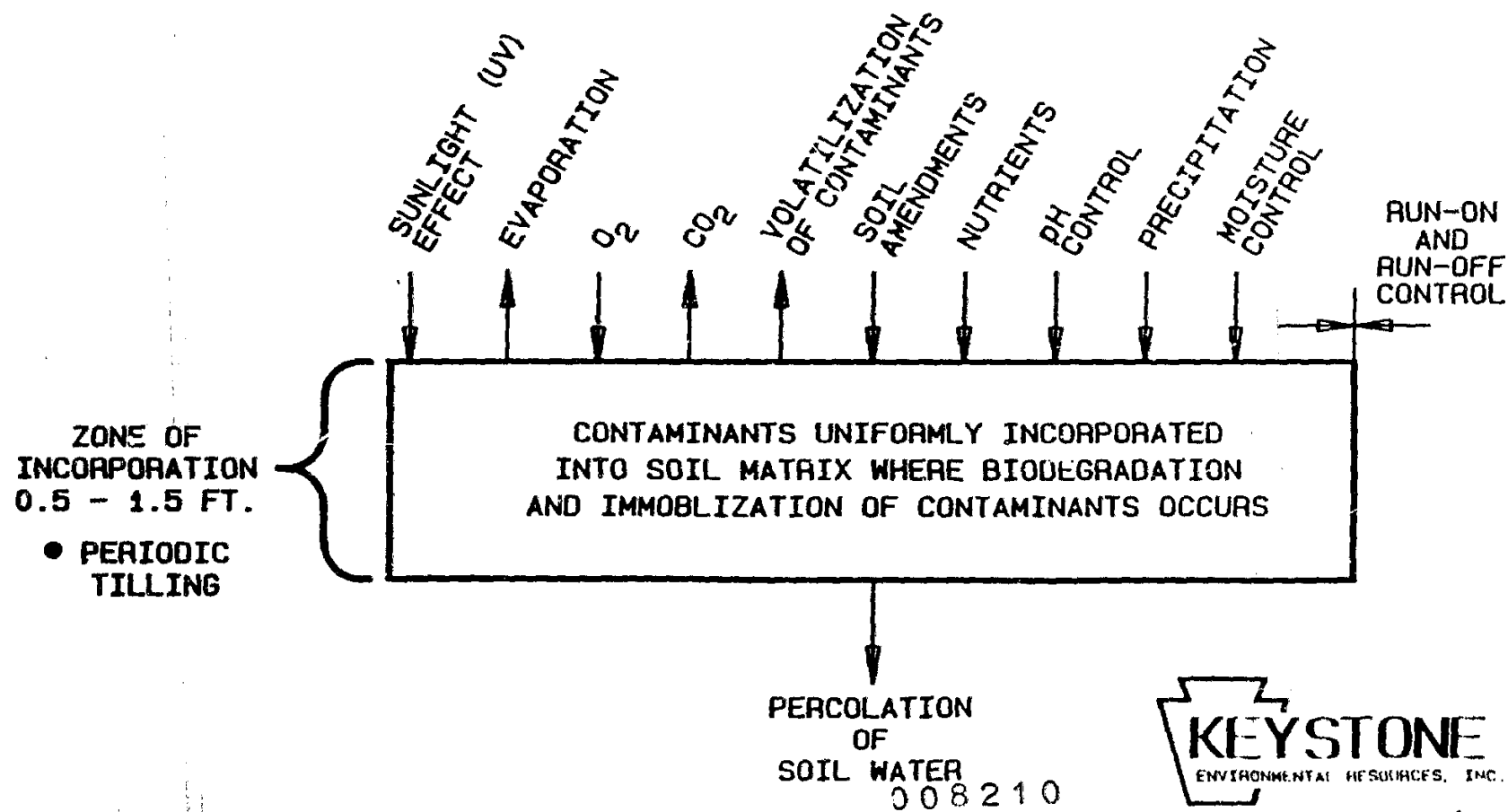
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**In Situ Treatment
Surface BioReclamation**

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FIGURE 1

INSITU SURFACE BIORECLAMATION TREATMENT PROCESS SCHEMATIC



biodegradation. Depending upon the particular chemicals to be treated and site specific conditions, volatilization can also account for soil reductions of volatile chemicals. At the same time these processes are occurring, photolysis may also be influencing the overall mechanism of soil treatment. Photolysis refers to photochemical reactions resulting from the absorption of light energy, generally from sunlight in natural systems. Since UV light does not penetrate very far into soils, photodegradation of soil contaminants is limited to soil surfaces. The addition of proton donors in the form of polar solvents, such as methanol, can enhance surface photodegradation of soil contaminants. For example, photolysis of dioxin (TCDD) on soil surfaces has been reported in the presence of methanol. In such systems, distinguishing among the different physical/chemical and biological processes is difficult.

PERFORMANCE:

In situ Surface BioReclamation treatment of soils is a proven technology for biological degradation of organic materials from petroleum refineries, wood treating facilities, chemical plants and many other industries which have wastes containing biodegradable organic and inorganic chemicals. Chemical contaminants are treated to the degree that they are immobilized in the soil and thus do not pose a potential risk via migration and resulting groundwater contamination. A properly designed and operated facility should be able to provide the following reductions in the following chemicals of interest:

- 1) 40 percent reduction of freon extractables.
- 2) 61 to 90 percent reduction in total PAH compounds, including 80 to 90 percent reduction in 2-ring PAH's, 82 to 93 percent reduction in 3-ring PAH's and 21 to 47 percent reduction in 4+ ring PAH's.
- 3) Converts ammonia to nitrates, which are readily used in soil oxidation reactions.
- 4) Degrades cyanides.
- 5) Metals are believed to be immobilized in the soil thereby preventing their migration to the ground water.

SOIL FLUSHING (In Situ Treatment)

MEDIUM:

Surface soil and subsurface soils/groundwaters.

PROCESS TYPE:

Physical/chemical processes including adsorption/desorption and enhanced solubilization of chemicals in solution.

RELATED SITE EXPERIENCE:

None.

APPLICABLE CHEMICALS OF INTEREST:

Water soluble compounds of interest, e.g. phenolics, are most applicable. Compounds having reasonable water solubility (volatile organics, two- and three-ring polynuclear aromatic hydrocarbons (PAHs)) may be applicable. Visible oils and PAHs could be applicable if surfactants or organic solvents can be used. Metals and insoluble cyanide salts are potentially extractable using acid or chelant aqueous wash.

TECHNOLOGY STATUS:

Emerging technology, bench-scale, pilot-scale, full-scale (limited).

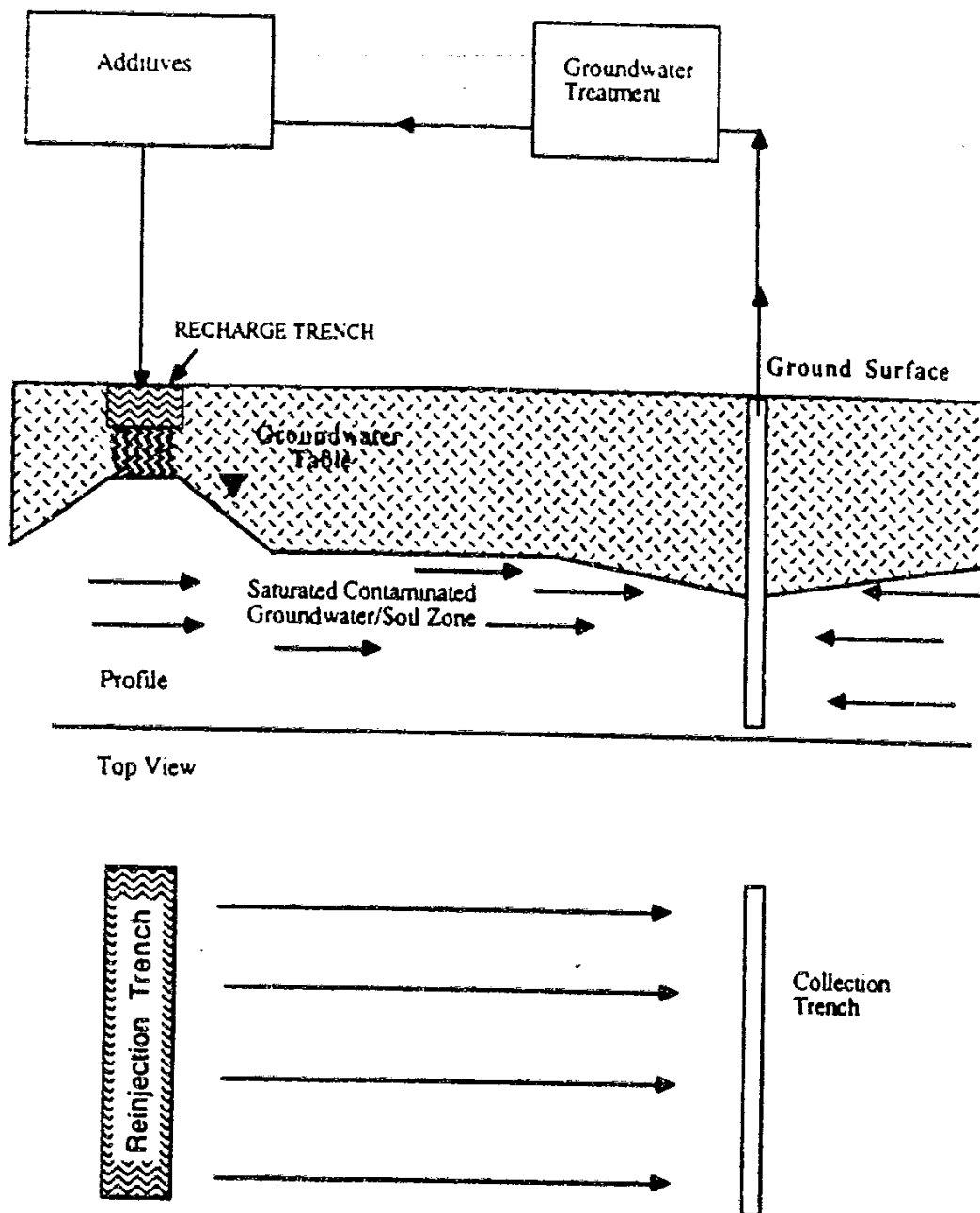
DESCRIPTION:

In situ soil flushing utilizes the concept of contaminant reductions in soils by the process of continuously passing a water solution through the contaminated soil zone and in effect washing the soils. As illustrated in Figure 1, water containing additives is continuously recirculated through the contaminated soil zone. As the water flows through the contaminated soil zone, a dynamic process occurs in which equilibrium conditions are continuously reestablished with soil contaminants desorbing off soil particles and solubilizing into solution. Once in solution, the contaminants are extracted along with the groundwater via pumping wells or collection trenches. The liquid solution is treated for reduction of the extracted chemicals of interest and then recycled for additional soil washing. Figure 1 depicts groundwater being collected and reinjected via trenches but wells can also be used.

The effectiveness of this technology requires an understanding of two basic mechanisms by which chemicals of interest are held within a soil environment. One is the chemical adsorption of contaminants to soil particles and the other involves the retention of contaminants within the interstices of the soil particles. These two mechanisms are influenced by the physical and chemical properties of both the soil matrix and the

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FIGURE 1
IN SITU SOIL FLUSHING TREATMENT PROCESS SCHEMATIC



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chemical contaminants of interest. To aid in enhanced chemical desorption and subsequent solubilization, the following additives may be added: (i) surfactants, (ii) chelating agents, (iii) acids or bases for pH control, (iv) organic solvents, (v) polymers and (vi) steam. The choice of the additive or additives for a particular application is primarily dictated by the chemical(s) type, the soil characteristics, and the compatibility of the additive(s) with the particular treatment system selected for the recirculated groundwater.

PERFORMANCE:

Extensive research and development type work has been conducted. Usually, in situ soil flushing is coupled with in situ biodegradation of chemicals of interest. For this reason, very limited data is available addressing in situ soil flushing as a separate technology. Present pilot work is focusing on enhanced oil removal, e.g. creosote, via in situ soil flushing with the aid of polymers and surfactants. This work is meeting with limited success.

For in situ soil flushing to be successful, the proper hydrogeologic conditions must exist with the application being highly site specific.

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CHEMICAL TREATMENT/FIXATION (In Situ Treatment)

MEDIUM:

Surface soils, subsurface soils/groundwaters.

PROCESS TYPE:

Physical/chemical processes including adsorption, complexation, precipitation and chemical oxidation/reduction.

RELATED SITE EXPERIENCE:

None.

APPLICABLE CHEMICALS OF INTEREST:

Inorganics, metals and some selected organics.

TECHNOLOGY STATUS:

For the reason that in situ chemical treatment/fixation is such a novel approach, no published sound scientific data is readily accessible. All published information available relates to chemical fixation processes in well controlled process reactors. To implement chemical treatment/fixation technologies in situ will require extensive basic research before full-scale implementation can proceed.

DESCRIPTION:

In situ chemical treatment/fixation of a contaminated area involves the use of a physical/chemical reaction to immobilize, destroy or detoxify a chemical or chemicals targeted in site soils and groundwaters. Chemical agents are generally applied to surface soil or are injected into subsurface soils/groundwaters where targeted chemicals are located. The major physical/chemical process categories applicable to in situ chemical treatment/fixation are:

- o Immobilization
- o Chemical Degradation
- o Volatilization Reduction

Immobilization includes a wide range of in situ treatment techniques designed to reduce the rate of release of contaminants from the soil so that resultant concentrations along pathways of exposure are held within acceptable limits. The primary immobilization mechanisms are adsorption, ion exchange, and precipitation.

Adsorption is potentially applicable to both organic and inorganic chemicals. Heavy metals in soil may be immobilized by mixing contaminated soil with a good adsorbent, or mixture of adsorbents, for the metals present, or with a metal complexing agent that binds

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the metal into a complex that strongly adsorbs to soil. Ion exchange mainly applies to metals where the cationic exchange capacity (CEC) of soil can be altered to increase its capacity to immobilize cationic compounds. Precipitation refers to a chemical balancing mechanism involving the addition of chemical agents to achieve precipitation of metals over complexation. The addition of sulfides, carbonates, phosphates and hydroxides to metal containing soils and groundwaters can immobilize the metals by precipitation of a highly insoluble compound.

Chemical degradation techniques refer to oxidation/reduction and polymerization reactions carried out in situ to transform soil contaminants into less toxic or less mobile products. Possible oxidizing agents include ozone or hydrogen peroxide. Possible reducing agents include catalyzed metal powders of iron, zinc or aluminum. If a soil is contaminated with polymerizable organics such as styrene, vinyl chloride, isoprene, acrylonitrile, or methyl methacrylate, mixing of iron and sulfates into the contaminated area may catalyze the in situ polymerization reaction. The polymers are commonly less toxic and less mobile than the monomers from which they are formed.

Volatilization reduction applies to suppressing chemical volatilization from soils with the added benefit of retaining compounds within the soil system for a long enough time to allow for other in situ treatment by one of the mechanisms or biodegradation. The most practical method of suppressing volatilization is to reduce the soil vapor pore volume through which the transport of vapors occurs. This can be done by compaction or addition of water to reduce the air-filled pore spaces within the soil relative to the water-filled pore spaces.

PERFORMANCE:

As previously stated, there has been very little operating experience with the use of in situ chemical treatment/fixation of contaminated surface soils and subsurface soils/groundwaters. Research should continue in this area for the reason that this technology eliminates the need for off-site disposal of contaminated materials. There is low risk of exposure to buried waste when injection and complete reaction is accomplished. However, the technology has limited applications and usually requires long-term land use restrictions at the site along with environmental monitoring. Also, reaction and immobilization may be incomplete, and there may be some desorption from repeated flushing by groundwater, resulting in subsequent off-site migration of the constituent.

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For in situ chemical treatment/fixation to be successful,
the proper hydrogeologic conditions must exist with the
application being highly site specific.

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In Situ Treatment
Chemical Treatment/Fixation

AIR/STEAM STRIPPING (In Situ Treatment)

MEDIUM:

Surface soils.

PROCESS TYPE:

Physical/chemical desorption volatilization and advection.

RELATED SITE EXPERIENCE:

Remediation of relatively small surface soil areas contaminated with volatile organics from solvent spills and leaky underground storage tanks.

APPLICABLE CHEMICALS OF INTEREST:

Volatile organic compounds, (VOC), volatile inorganics.

TECHNOLOGY STATUS:

Emerging technology, bench-scale testing, pilot-scale testing, full-scale design and implementation.

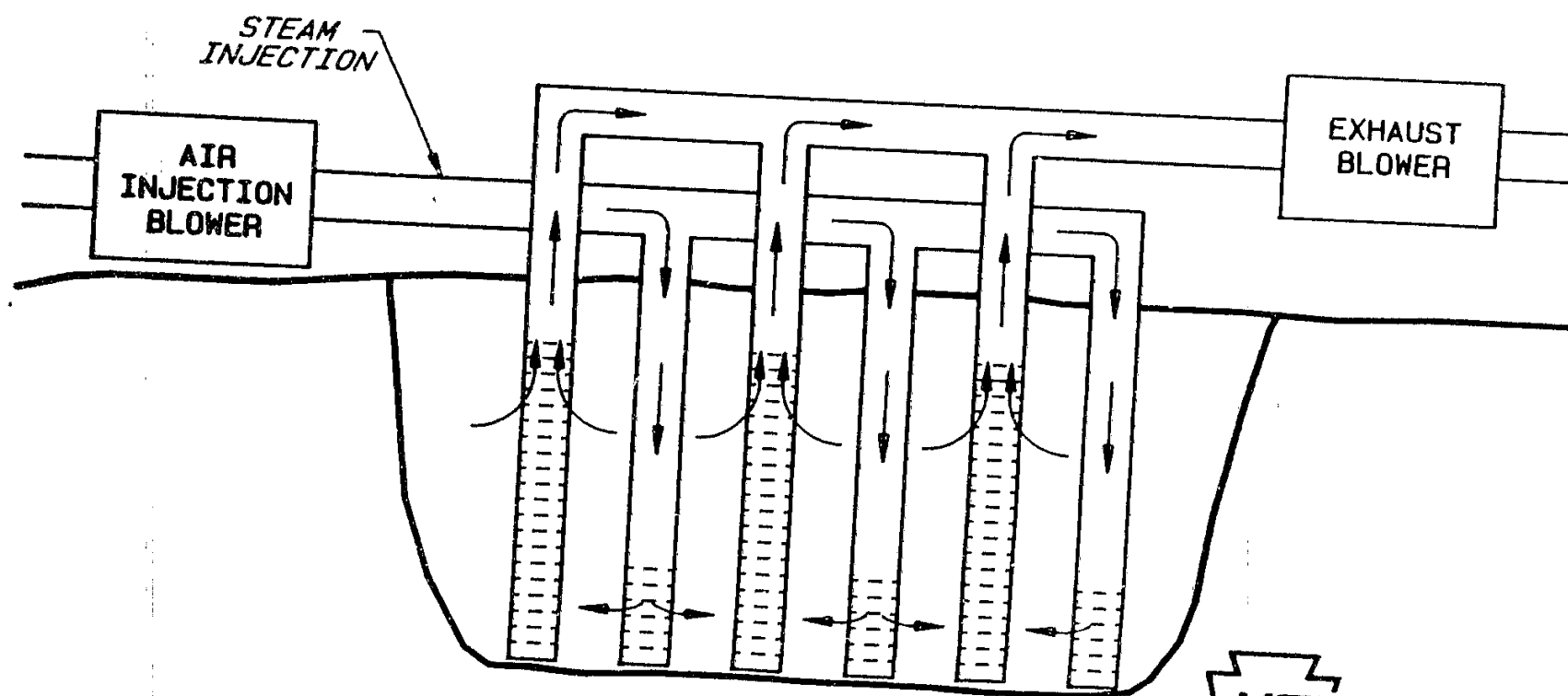
DESCRIPTION:

In situ air/steam stripping is an emerging site restoration technology proven effective for the removal of volatile organic compounds (VOC), e.g. benzene, toluene, and xylene, from contaminated soils in the unsaturated zone as a means of source control. The technology may also have some application for the removal of volatile inorganics, e.g. hydrogen cyanide and hydrogen sulfide, from soil. The process involves the removal of volatile chemicals from soil by mechanically venting air and/or steam through the unsaturated soil layer. The contaminated soils are gradually remediated as the volatiles are stripped from the soil. Most applications have dealt with air stripping though steam could also be used. Heated air passing through the soil may enhance the rate of chemical desorption and subsequent volatilization above that which would be achieved by air stripping alone.

The processes which influence soil stripping include: (i) adsorption and desorption of VOC from the soil particles, (ii) the volatilization of the desorbed VOC, and (iii) the movement of contaminated air through soil voids by advection. Two key factors that affect these processes and enhance the success of soil stripping are low soil moisture to provide for adequate advection and volatility of the chemicals to be stripped. As illustrated in Figure 1, these processes are mechanically controlled by the continuous injection and extraction of air or steam through the soil. Steam could be injected into the injection line as illustrated. Typically, in situ soil venting systems are operated at a negative pressure which serves to enhance chemical volatilization. While Figure 1

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FIGURE 1
AIR / STEAM STRIPPING INSITU TREATMENT PROCESS SCHEMATIC



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shows wells as point injectors and collectors, trenches can also be used. After collection, the air is drawn to the blower unit where the various collection wells or trenches are tied into a manifold. Each incoming line can be equipped with a vacuum gauge and valve so the system can be fine tuned to meet any air discharge requirements. Treatment of the vented gas is also an option.

PERFORMANCE:

Process shown to be technically viable for the significant reduction of trichloroethylene (TCE) in soil resulting from leaky gasoline storage tanks. Soil venting through air/steam stripping offers a potentially low-cost treatment method that is ideal for conditions where some cleanup is necessary and soil excavation may not be economically justified or is not practical because there are buildings and process equipment over the contaminated soil.

For in situ air/steam stripping to be successful, the proper hydrogeologic conditions must exist with the application being highly site specific.

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VITRIFICATION (In Situ Treatment)

MEDIUM: Subsurface soils.

PROCESS TYPE: Thermal.

RELATED SITE EXPERIENCE: Pilot scale treatment of polychlorinated biphenyls (PCB) contaminated surface soil.

APPLICABLE CHEMICALS OF INTEREST: Metals, phenolics, polynuclear aromatic hydrocarbons, volatile organics, pesticides, PCB, inorganics. Not applicable if organic content is high.

TECHNOLOGY STATUS: Developing technology, bench-scale and pilot-scale.

DESCRIPTION:

Vitrification is a highly energy intensive process which converts contaminated soil into a glass (amorphous) and crystalline mineral matrix that has chemical durability properties similar to granite. Vitrification, at typical soil melting temperatures between 1100 and 1600°C, will destroy organics and fix non-volatile metals into a nonleachable solidified melt. The most commonly proposed vitrification technique is ISV (in situ vitrification). In this procedure, the contaminated soil is not excavated but is vitrified in place. The energy required to heat and melt the soil is supplied by applying electric current to electrodes buried in the soil. Since the molten soil is conductive, it is heated by its own resistance (joule heating). For this process to be cost effective, the contamination must be deep (at least 6 feet) and soil moisture must be less than 25 percent. Large sites can be treated by successive vitrification of adjacent blocks or zones of soil. Any soil vitrification process will produce off-gas containing steam, volatile metals, products from combustion of any organics in the soil as well as the organics themselves, and some particulates. This off-gas must be collected and treated.

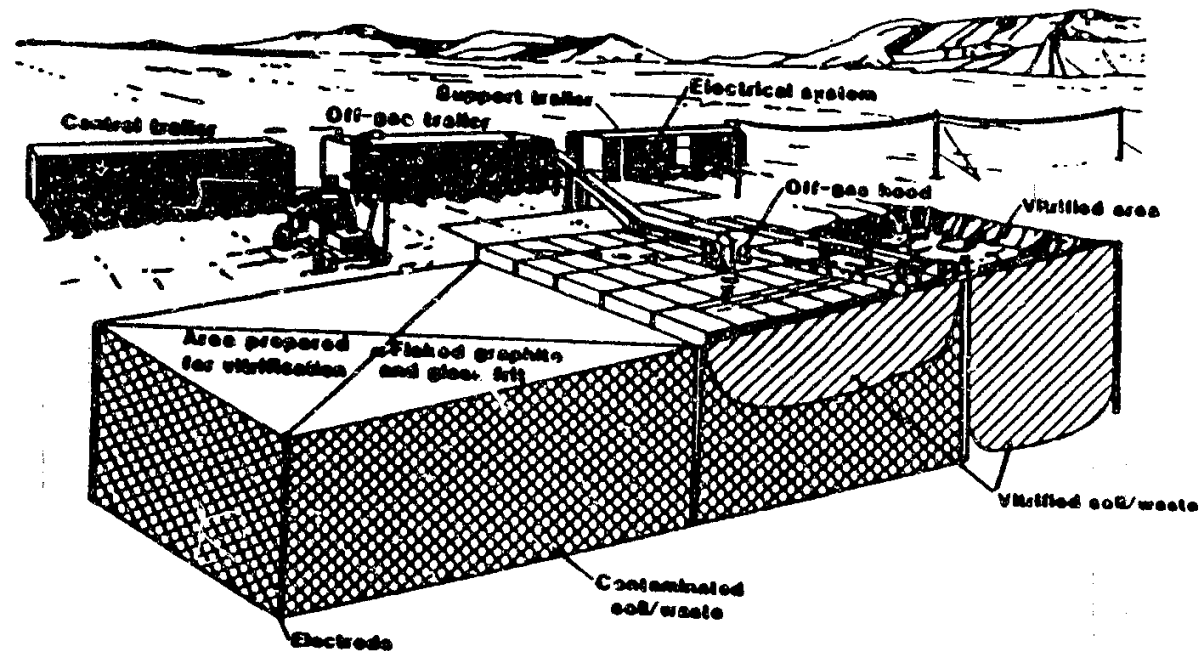
In situ vitrification (ISV) is essentially a batch process where soil/waste is vitrified in large blocks. The technique in Figure 1 shows four carbon or molybdenum electrodes placed in the soil 10 to 18 feet apart. The electrodes are connected (in an X pattern) by 2-inch-deep trenches filled with glass frit and graphite. The square of soil is covered by a fume hood that is connected to a gas scrubbing/emission control system. When power (up to 3750 kW at 4160 V) is applied to the four electrodes, the glass frit/graphite mixture initiates

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In Situ Treatment
Vitrification

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SOURCE: Gas Research Institute, October 1987

Figure 1
IN SITU VITRIFICATION OPERATION SCHEMATIC

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conductance and is quickly heated to soil melting temperatures (1100 to 1600°C). As power is continued to the system, the soil around the molten glass/graphite is melted and becomes conductive. The size of the melt zone increases until it includes not only the volume between the electrodes, but extends slightly beyond them. The depth of the melt should be at least 6 feet and the ISV process becomes somewhat less costly as the depth increases. In ISV, the soil block is melted from the top down and as the melt zone progresses, it heats the adjacent soil. This volatilizes or pyrolysis any organic compounds that are present. The volatiles, any pyrolysis products, and the steam from the soil moisture pass through the melt and are heated to the melt temperature. The organics are then oxidized when they contact the hot air directly above the melt. These off-gases are collected by the fume hood and treated in the scrubbing system. A typical scrubbing system would include quenching the hot gases, acid gas and particulate removal in a venturi scrubber, and possibly a fine particulate removal device such as a baghouse filter or a mist eliminator.

PERFORMANCE:

In situ vitrification has been demonstrated through a pilot-scale test in which over 400 tons of PCB contaminated soil was treated. Laboratory bench-scale vitrification testing of soil with an initial PCB concentration of approximately 500 mg/kg achieved an overall destruction removal efficiency (DRE) greater than 99.9 percent for methyl ethyl ketone, formaldehyde, toluene, trichlorethylene and carbon tetrachloride.

For in situ vitrification to be successful, the proper hydrogeologic conditions must exist with the application being highly site specific.

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3.2 ON-SITE WATER TREATMENT
ACTIVATED SLUDGE
AERATION
FIXED BED
BIOFLOWSM
SEQUENCING BATCH REACTOR
TRICKLING FILTER
AIR STRIPPING
STEAM STRIPPING
BIOFILTRATIONSM
CARBON ADSORPTION
CHEMICAL OXIDATION
DISSOLVED AIR FLOTATION
EVAPORATION
FILTRATION
PHYSICAL/CHEMICAL GRAVITY SEPARATION
ION EXCHANGE
NEUTRALIZATION
UV CHEMICAL OXIDATION
PHOTOLYSIS
REVERSE OSMOSIS
SOLVENT EXTRACTION
WET AIR OXIDATION
SONIC TREATMENT

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ACTIVATED SLUDGE (Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface water and process wastewaters.

PROCESS TYPE:

Biological Oxidation

RELATED SITE EXPERIENCE:

Petroleum industry, wood treating sites, coking and coal tar distillation sites, manufactured gas plant sites, chemical plants and other industries. Commonly used to treat industrial process wastewaters.

APPLICABLE CHEMICALS OF INTEREST:

Conventional pollutants, phenolics, oil and grease, polynuclear aromatic hydrocarbons (PAH), volatile organics, biodegradable inorganics, polychlorinated biphenyls (PCB) and dioxins/furans.

TECHNOLOGY STATUS:

Well established technology for the treatment of industrial "conventional" parameters. Bench-scale, pilot-scale, full-scale.

DESCRIPTIONS:

The activated sludge process utilizes a biological slurry containing an active mass of bacteria to achieve microbial oxidation and assimilation (treatment) of wastewater. A typical schematic diagram of a conventional activated sludge system is shown in Figure 1. Raw wastewater (influent) entering the aeration basin normally receives some pretreatment. This pretreatment is typically for the removal of easily settled solids or other suspended matter, such as oil.

Following pretreatment, the influent is introduced into an aeration basin where it comes into contact with a bacterial culture which is maintained in suspension. The aeration tank contents are referred to as the mixed liquor. Under proper conditions, the microorganisms convert the organic wastes into microbial cells, carbon dioxide and water.

Industrial aeration basins typically have surface and/or deep impellers in order to provide complete mixing of the influent and mixed liquor. An oxygen supply adds oxygen to the aeration basin to provide an aerobic condition for the biological population. The pH of the incoming wastewater or mixed liquor must be controlled in order to provide proper conditions for the microorganisms. A neutral pH is usually required for normal activated sludge systems. The influent to the

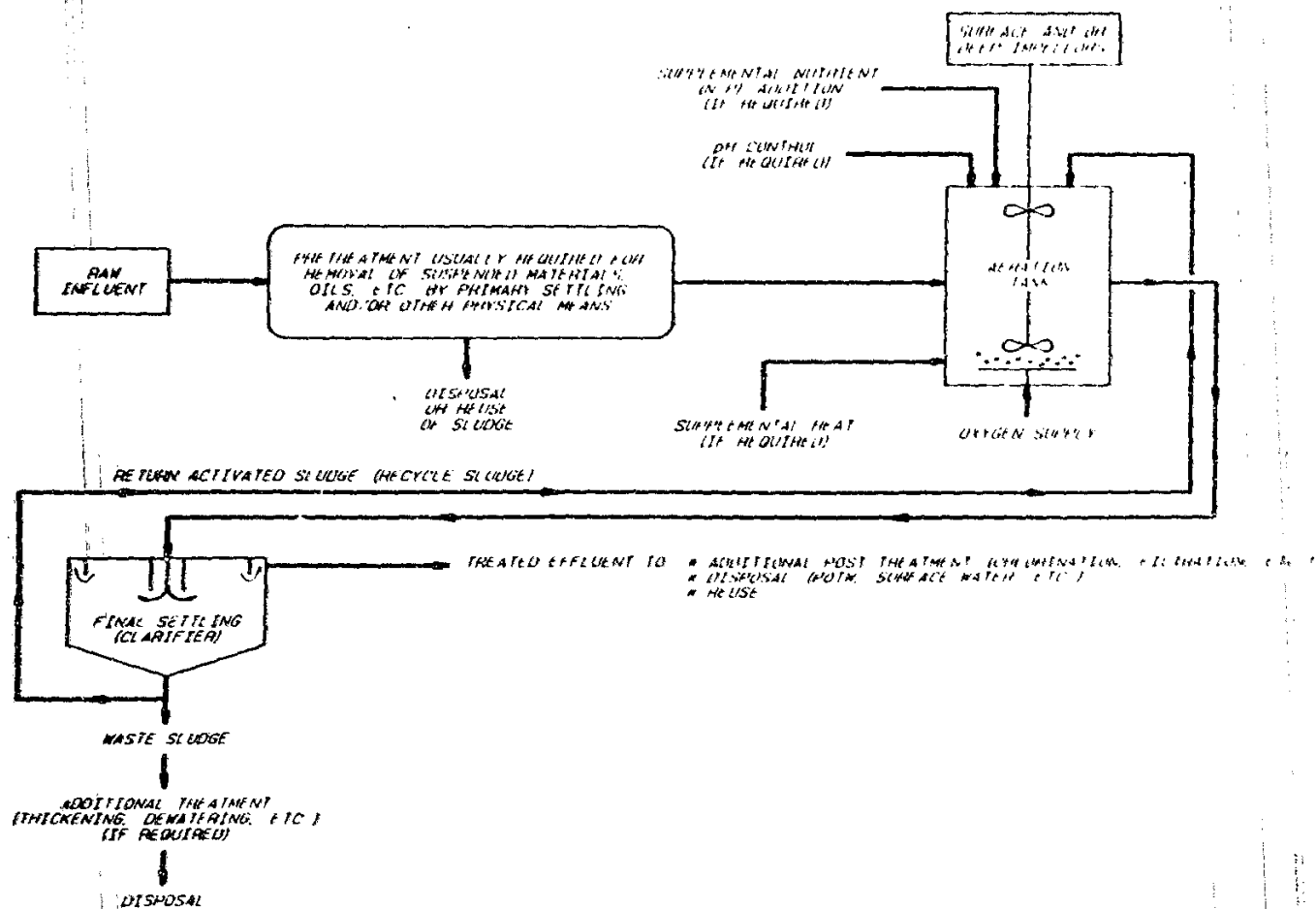
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Ex Situ Treatment
Activated Sludge

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FIGURE 1
SCHEMATIC DIAGRAM OF A CONVENTIONAL ACTIVATED SLUDGE SYSTEM



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aeration base or mixed liquor in the aeration tank can be pH adjusted by adding caustic or acid to bring the pH to near neutral. Supplemental nutrients in the form of nitrogen and/or phosphorus (N,P) may be required if the raw wastewater stream is deficient of these nutrients. In colder climates supplemented heat may also be required in order to maintain an acceptable temperature range for biological activity.

One of the important parameters for the treatment of the incoming wastewater is its retention time within the aeration tank. This is referred to as the hydraulic retention time (HRT), and is defined as the ratio of the aeration tank volume (V) to the influent wastewater flowrate (Q). Another important parameter is the solids retention time (SRT). The SRT refers to the amount of time the biomass (biological solids) remains in the aeration tank-settling system, it is also referred to as the mean bacterial cell residence time.

The treated mixed liquor is passed from the aeration tank to a settling tank (clarifier) after a specified HRT. The microbial solids are then separated from the treated effluent in the clarifier. The treated effluent, which is typically low in suspended solids concentration, is ready for discharge. Industrial discharge from activated sludge systems may be sent to a public owned treatment works (POTW), surface water discharge (NPDES), receive additional treatment, or reused.

The settled sludge from the clarifier is concentrated and a portion is recycled to the aeration tank with the remaining portion disposed (wasted). The portion of sludge returned to the aeration basin is referred to as recycle sludge, and is used to maintain a desired concentration of organisms in the basin. The ratio of the recycled sludge flowrate to the wastewater flowrate is referred to as the recycle ratio (r). The wasted portion (waste sludge) of sludge corresponds to the new growth of cell tissue or solids produced from the microorganisms continually synthesizing. Wasted sludge usually receives some additional treatment (thickening, dewatering) prior to its ultimate disposal. The degree of wasting ultimately determines the system SRT. At a low wasting rate, the SRT would be relatively high due to the fact that solids will remain in the system longer.

PERFORMANCE:

Activated sludge treatment is a proven technology for removal of biodegradable organics from domestic wastewaters, and ground waters/surface waters contaminated with coal tar based chemicals. A properly designed and operated activated sludge treatment process can generally achieve:

- o Greater than 99 percent removal of phenolics,
- o Between 80 to 99+ percent removal of polynuclear aromatic hydrocarbons and naphthalene,
- o Greater than 99 percent removal of purgeable aromatics,
- o Between 90 to 99+ percent removal of oil and grease,
- o Between 80 to 99+ percent removal of total organic carbon,
- o Between 90 to 99+ percent removal of ammonia and non-complexed cyanide and
- o Greater than 99 percent removal of thiocyanate.

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**Ex Situ Treatment
Activated Sludge**

AERATION TANK
(Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE:

Biological Oxidation

RELATED SITE EXPERIENCE:

Petroleum industry, wood treating sites, chemical plants and other industries. Commonly used to treat industrial process wastewaters which are applicable to biological treatment.

APPLICABLE CHEMICALS OF INTEREST:

Conventional pollutants, total organic carbon, phenolics, oil and grease, polynuclear aromatic hydrocarbons (PAH), volatile organics, and polychlorinated biphenyls (PCB).

TECHNOLOGY STATUS:

Well established technology for the treatment of industrial "conventional" parameters when an effluent suspended solid concentration in the 100 to 1000 ppm range is permissible. Bench-scale, pilot-scale, full-scale.

DESCRIPTION:

Figure 1 shows a basic schematic diagram of an aeration tank system. The raw wastewater (influent) normally receives some pretreatment prior to entering the aeration basin. This pretreatment is typically for the removal of easily settled solids or other suspended matter such as oil. Pretreatment may include gravity settling along with chemical additions to enhance the removal of these materials (chemical additions mainly for oil removal).

The pretreated influent is then introduced into a reactor (aeration basin) where it comes into contact with a bacterial culture which is maintained in suspension. The aeration tank contents are referred to as the mixed liquor. Under proper conditions, the microorganisms convert the organic wastes into microbial cell tissue, carbon dioxide and water.

Aeration basins typically have surface and/or deep impellers in order to provide complete mixing of the influent and mixed liquor. Oxygen is added to the aeration basin to maintain an aerobic condition for the biological population. The pH of the incoming wastewater or the mixed liquor must be controlled in order to provide proper conditions for the microorganisms. A neutral pH is usually required for

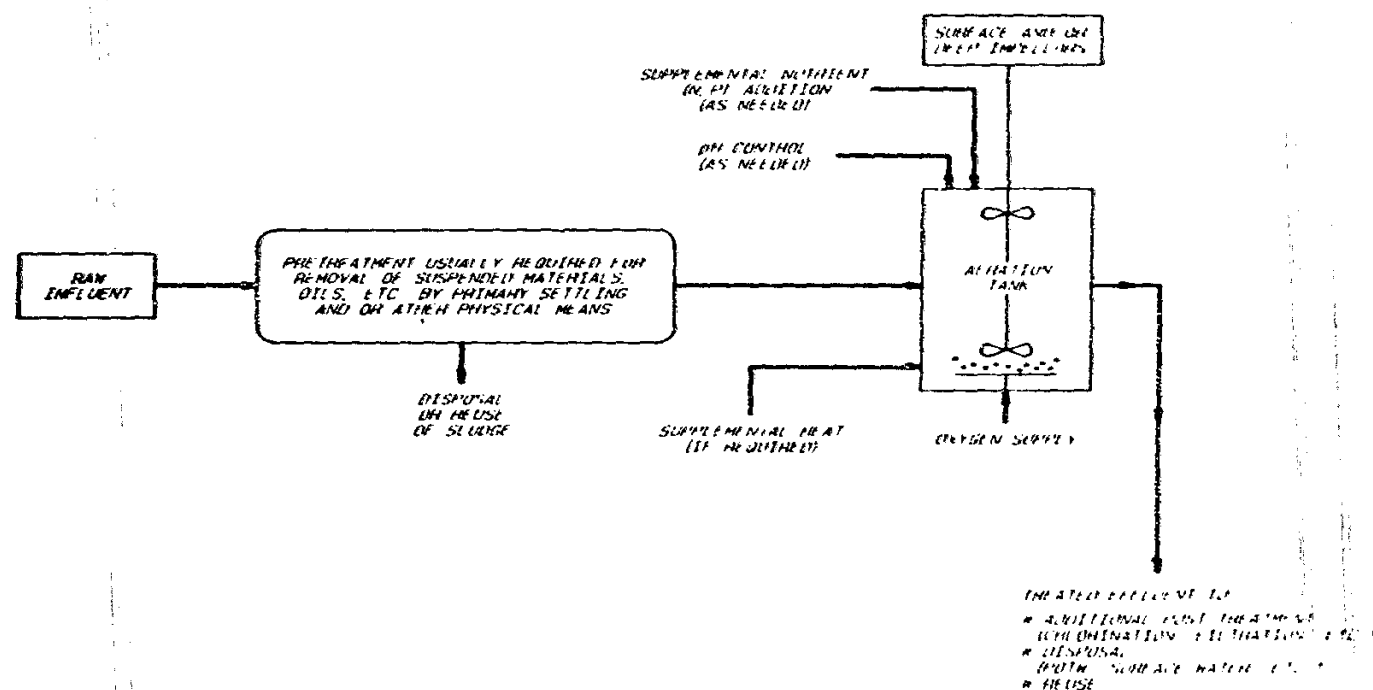
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1

**Ex Situ Treatment
Aeration Tank**

008229

FIGURE 1
SCHEMATIC DIAGRAM OF AN AERATION TANK SYSTEM



008230

normal aeration tank operation. The influent to the aeration basin or mixed liquor in the aeration tank can be pH adjusted by adding caustic or acid to bring the pH to near neutral. Supplemental nutrients in the form of nitrogen and/or phosphorous (N,P) may be required if the raw wastewater stream does not contain sufficient amounts of these nutrients. In colder climates supplemental heat may also be required in order to maintain an acceptable temperature range for the microorganisms.

The treated mixed liquor is sent from the aeration tank to discharge or to additional treatment, e.g. solids removal. Additional treatment for solids removal is only necessary if there is a limit on the suspended solids concentration in the treated effluent being discharged. Industrial discharges from aeration tank systems may be sent to a public owned treatment works (POTW), surface water discharge (NPDES), or reused.

PERFORMANCE:

Aeration tank treatment is a proven technology for removal of biodegradable organics from domestic wastewaters and ground waters/surface waters contaminated with coal tar based chemicals. Aeration tank treatment is similar to activated sludge treatment with the exception that the mixed liquor suspended solids are discharged with the effluent rather than recycled. A properly designed and operated aeration tank treatment process can generally achieve:

- o greater than 99 percent removal of phenolics,
- o between 50 to 99+ percent removal of polynuclear aromatic hydrocarbons and naphthalene,
- o between 60 to 99 percent removal of oil and grease and
- o between 80 to 98 percent removal of total organic carbon.

DRAFT

**FIXED BED
(Ex In Situ Treatment)**

MEDIUM: Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE: Biological Oxidation

RELATED SITE EXPERIENCE: Wood treating sites, coking and coal tar distillation sites, and chemical plants.

APPLICABLE CHEMICALS OF INTEREST: Conventional pollutants, polynuclear aromatic hydrocarbons (PAH), phenolics, volatile organics, biodegradable inorganics, polychlorinated biphenyls (PCB) and dioxins/furans.

TECHNOLOGY STATUS: Established technology that has been used in the wastewater treatment industry for more than 50 years. However, its use was minimal until recently when more sophisticated designs were developed. Bench-scale, pilot-scale, full-scale.

DESCRIPTION: The fixed bed process is effective in treating wastewaters that contain less than 100 ppm in organics and are becoming increasingly popular as regulations governing wastewater discharges become more stringent. Several designs developed in recent years have been proven to work efficiently. Typical designs include column type structures with synthetic packing providing the contact area necessary for media growth.

Fixed bed technology involves the process of degrading wastewater contaminants through microorganisms that are attached to a fixed media such as synthetic packing, wire mesh, or filter stone. The basic design of a fixed bed process is similar to that of a trickling filter except that the media is submerged in the wastewater. Both aerobic and anaerobic decomposition of biodegradable wastewater contaminants can be performed with a fixed bed system. An aerobic fixed media process requires an external oxygen source. Several different designs and operating modes exist for fixed bed systems. Figure 1 represents a schematic flow diagram of a typical fixed bed process.

Following primary settling and/or oil/water separation, wastewater is pumped into the fixed bed biological reactor from either the top or bottom. Air is supplied through the base of the reactor if aerobic conditions are

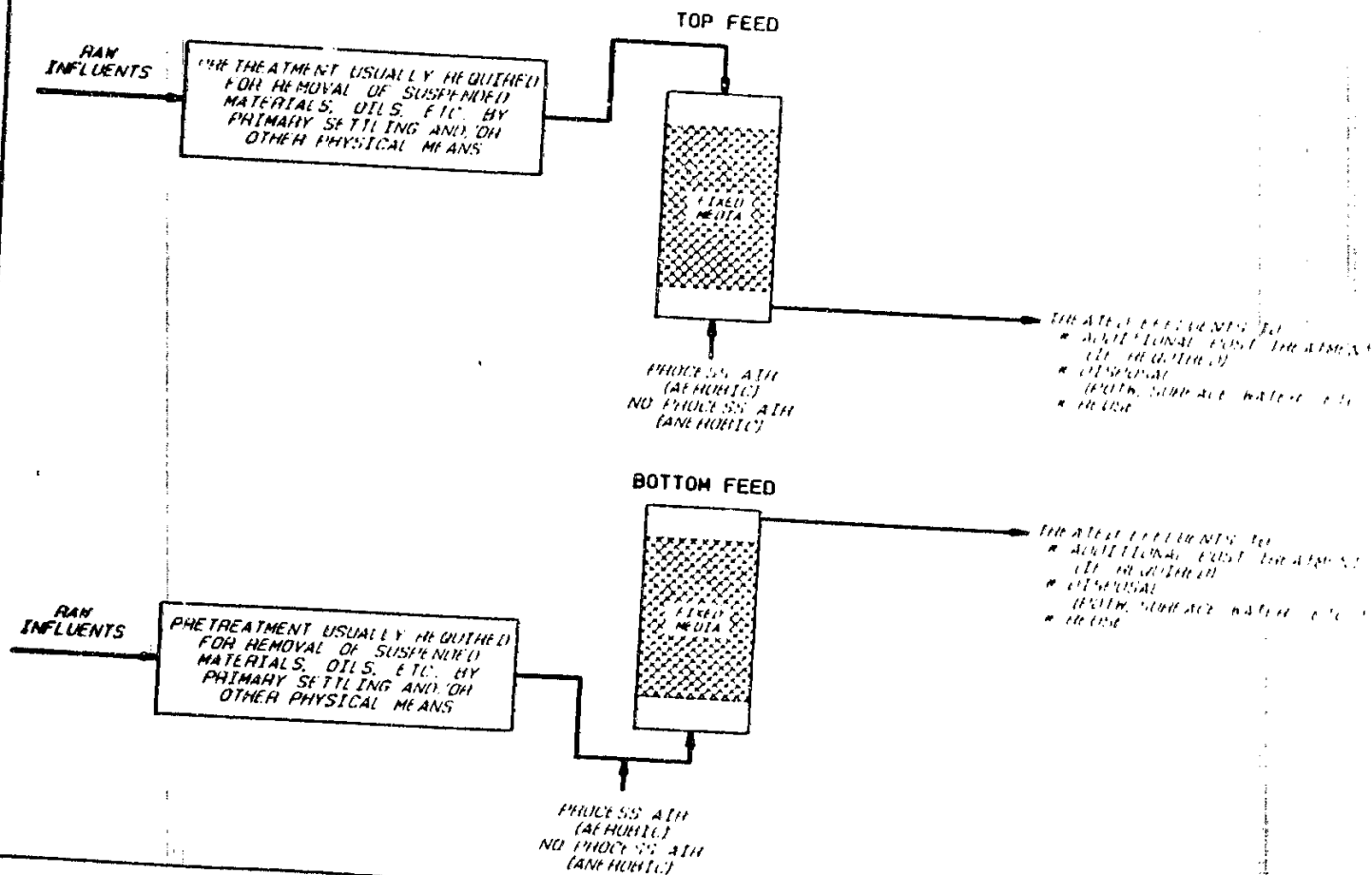
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**Ex Situ Treatment
Fixed Bed**

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FIG. 1 SCHEMATIC DIAGRAM OF A BIOLOGICAL FIXED-BED TREATMENT SYSTEM



008233

required. The treated effluent can flow by gravity or be pumped for discharge, reuse, or additional treatment.

PERFORMANCE:

Fixed bed treatment is a proven technology for removal of biodegradable organics from domestic wastewaters and groundwaters contaminated with coal tar based chemicals. A properly designed and operated fixed bed treatment system has been shown to achieve:

- o Greater than 90 percent removal of phenolics,
- o Greater than 80 percent removal of polynuclear aromatic hydrocarbons and
- o Approximately 60 percent removal of total organic carbon.

008234

BIOFLOWSM
(Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface waters and polishing treatment for process wastewaters.

PROCESS TYPE:

Adsorption/desorption and aerobic or anaerobic biological oxidation.

RELATED SITE EXPERIENCE:

Wood treating industry.

APPLICABLE CHEMICALS OF INTEREST:

Conventional pollutants, phenolics, polynuclear aromatic hydrocarbons (PAH), volatile organics, biodegradable inorganics, polychlorinated biphenyls (PCB) and dioxins/furans.

TECHNOLOGY STATUS:

Developing technology. Bench-scale, pilot-scale.

DESCRIPTION:

BioFlowSM is a proprietary process developed by Keystone Environmental Resources, Inc. for the treatment of slightly contaminated pumped groundwaters and polishing treatment of process wastewaters. In general, it is a biological process which combines the treatment capabilities of contaminant adsorption and biodegradation in a vessel type reactor.

As illustrated in Figure 1, an influent stream containing chemicals of interest is treated biologically in a reactor. Added chemicals of interest are first adsorbed onto media in the reactor. Conditions are maintained in the reactor to achieve subsequent biodegradation of the adsorbed chemicals which in effect biologically regenerates the adsorption media. Proper conditions are maintained in the reactor via supplemental nutrients and chemicals added in the influent stream. A certain recirculation of effluent is also provided to achieve the proper reactor hydraulic retention time (HRT). The treated effluent flowrate corresponds to the influent flowrate.

PERFORMANCE:

Through bench- and pilot-scale testing, Keystone has demonstrated that BioFlowSM is a proven technology for removal of adsorbable and biodegradable chemicals from water and wastewater effluents. While a BioFlowSM treatment unit can be designed and operated to achieve different effluent requirements, the data presented in Table 1 gives results of bench-scale work examining treatment of pumped contaminated groundwater from a previously operated wood treating site. These results support that BioFlowSM reactor treatment offers a viable polishing

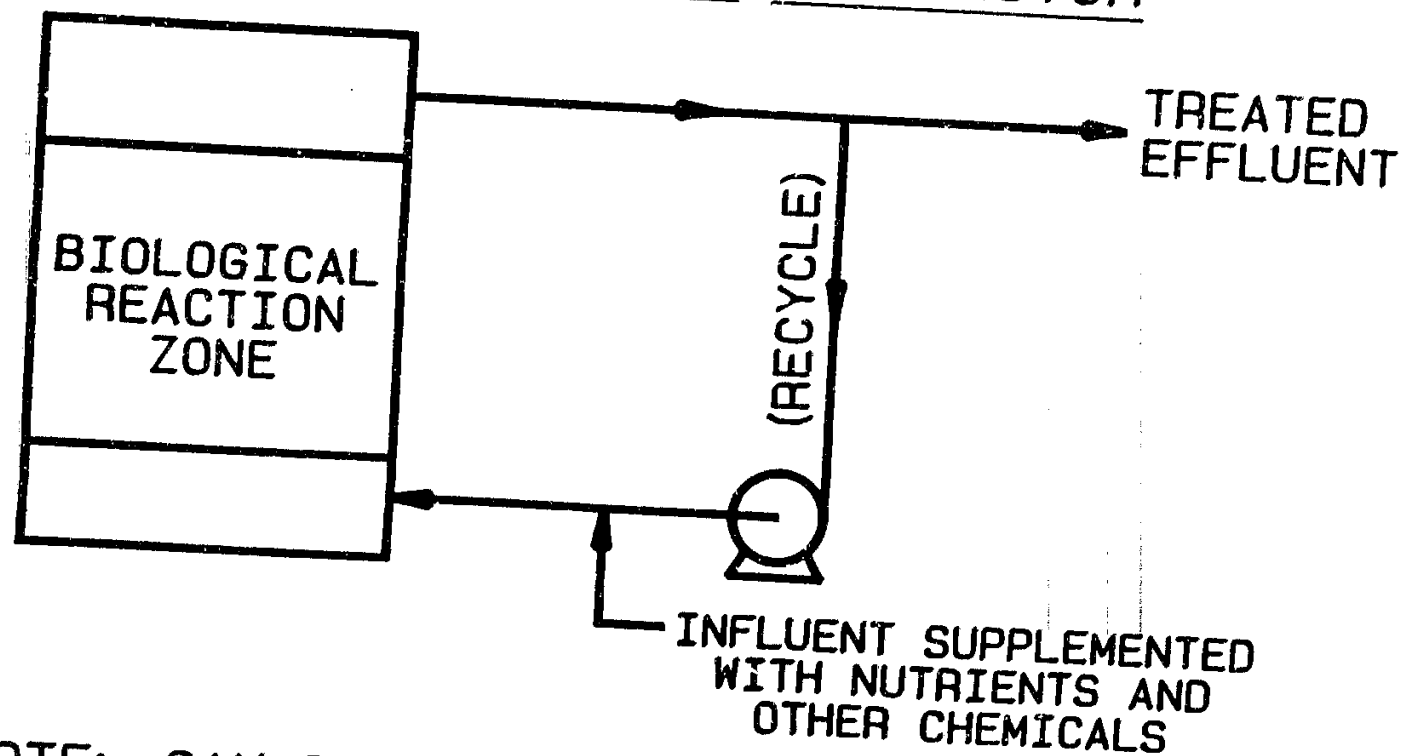
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Ex Situ Treatment
BioFlowSM

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FIGURE 1
SCHEMATIC DIAGRAM OF
KEYSTONE'S BioFLOWSM REACTOR



NOTE: CAN BE OPERATED UNDER BOTH
AEROBIC AND ANAEROBIC CONDITIONS.

008236

TABLE 1

**KEYSTONE'S BIOFLOWSM TREATMENT
PERFORMANCE HIGHLIGHTS**

PARAMETER	INFLUENT CONCENTRATION	EFFLUENT CONCENTRATION	PERCENT REDUCTION
TOC	21.3	2.2	90
BOD-TOTAL	15.5	< 1.00	> 94
BOD-SOLUBLE	---	< 1.00	---
COD-TOTAL	65.0	11.0	83
COD-SOLUBLE	---	< 10.0	---
OIL & GREASE	< 6.00	< 6.0	---
PHENOLS (4-AAP)	0.354	< 0.005	> 99
TOTAL DISSOLVED SOLIDS	161.0	125.0	22
VOLATILE DISSOLVED SOLIDS	38.0	6.0	84
FIXED DISSOLVED SOLIDS	123.0	119.0	3
PENTACHLOROPHENOL	8.5	0.00145	> 99.9
PAH COMPOUND (ug/l)			
ACENAPHTHENE	141	< 2.00	> 98
ACENAPHTHYLENE	114	< 2.00	> 98
ANTHRACENE	12	< 0.500	> 96
BENZO (a) ANTHRACENE	0.811	< 0.020	> 97
BENZO (a) PYRENE	0.332	< 0.020	> 97
BENZO (b) FLUORANTHENE	0.518	< 0.020	> 96
BENZO (g, h, i) PERYLENE	0.457	< 0.050	> 89
BENZO (k) FLUORANTHENE	0.158	< 0.020	> 87
CARBAZOLE (ug/l)	112	< 2.00	> 98
CHRYSENE	0.8	< 0.150	> 81
DIBENZ (ah) ANTHRACENE	0.347	< 0.030	> 91
FLUORANTHENE	11.8	< 0.200	> 98
FLUORENE	92.5	< 0.200	> 99
INDENO (123-cd) PYRENE	0.249	< 0.050	> 80
NAPHTHALENE	125	< 2.00	> 98

NOTE: All results are expressed in mg/L unless otherwise noted. < values correspond to detectable concentrations.

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TABLE 1(Continued)

KEYSTONE'S BIOFLOWSM TREATMENT
PERFORMANCE HIGHLIGHTS

<u>PARAMETER</u>	<u>INFLUENT CONCENTRATION</u>	<u>EFFLUENT CONCENTRATION</u>	<u>PERCENT REDUCTION</u>
PHENANTHRENE	73.8	< 0.500	> 99
PYRENE	8.77	< 0.200	> 98
TOTAL PAH	695	< 0.00	> 99.9

NOTE: All results are expressed in mg/L unless otherwise noted. < values correspond to detectable concentrations.

008238

treatment technology with non-detectable concentration levels of phenols (4-AAP) and PAHs being achieved.

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2

Ex Situ Treatment
BioFlowSM

SEQUENCING BATCH REACTOR (Ex Situ Treatment)

<u>MEDIUM:</u>	Contaminated pumped groundwater, segregated surface waters and process wastewaters.
<u>PROCESS TYPE:</u>	Biological oxidation
<u>RELATED SITE EXPERIENCE:</u>	Treatment of contaminated groundwater from a hazardous waste site and treatment of an industrial landfill leachate.
<u>APPLICABLE CHEMICALS OF INTEREST:</u>	Conventional pollutants, phenolics, polynuclear aromatic hydrocarbons (PAHs), volatile organics, biodegradable inorganics, polychlorinated biphenyls (PCB) and dioxins/furans.
<u>TECHNOLOGY STATUS:</u>	Established technology for treatment of domestic wastewaters but industrial applications have been limited. Bench-scale, pilot-scale, full-scale.
<u>DESCRIPTION:</u>	<p>Sequencing batch reactor (SBR) biotreatment is essentially a fill-and-draw activated sludge process. Each tank in the SBR system is filled with wastewater during a discrete period of time and then is operated in a batch treatment mode. After treatment, the mixed liquor is allowed to settle for a predetermined amount of time and then a specified volume of clarified supernatant is withdrawn from the tank. The volume of supernatant removed during the withdraw cycle is dependent upon the desired hydraulic retention time (HRT) and the capacity of the SBR tank. During the filling, treatment, sedimentation and withdrawal phases of the SBR process, the raw wastewater flow is directed to another SBR tank in the system, as in a multiple tank configuration. After the withdrawal phase of treatment is completed, the wastewater is drawn from the storage tank and allowed to flow into the SBR system. Figure 1 presents a single tank in each of the five periods of one complete cycle.</p> <p>Following treatment in the SBR system, the effluent can be discharged, reused or receive additional treatment. The waste sludge can be reused or disposal of.</p>
<u>PERFORMANCE:</u>	Sequential Batch Reactor (SBR) treatment is a proven technology for removal of biodegradable organics from domestic wastewaters. In addition, limited testing has shown that the SBR process is also effective in removing

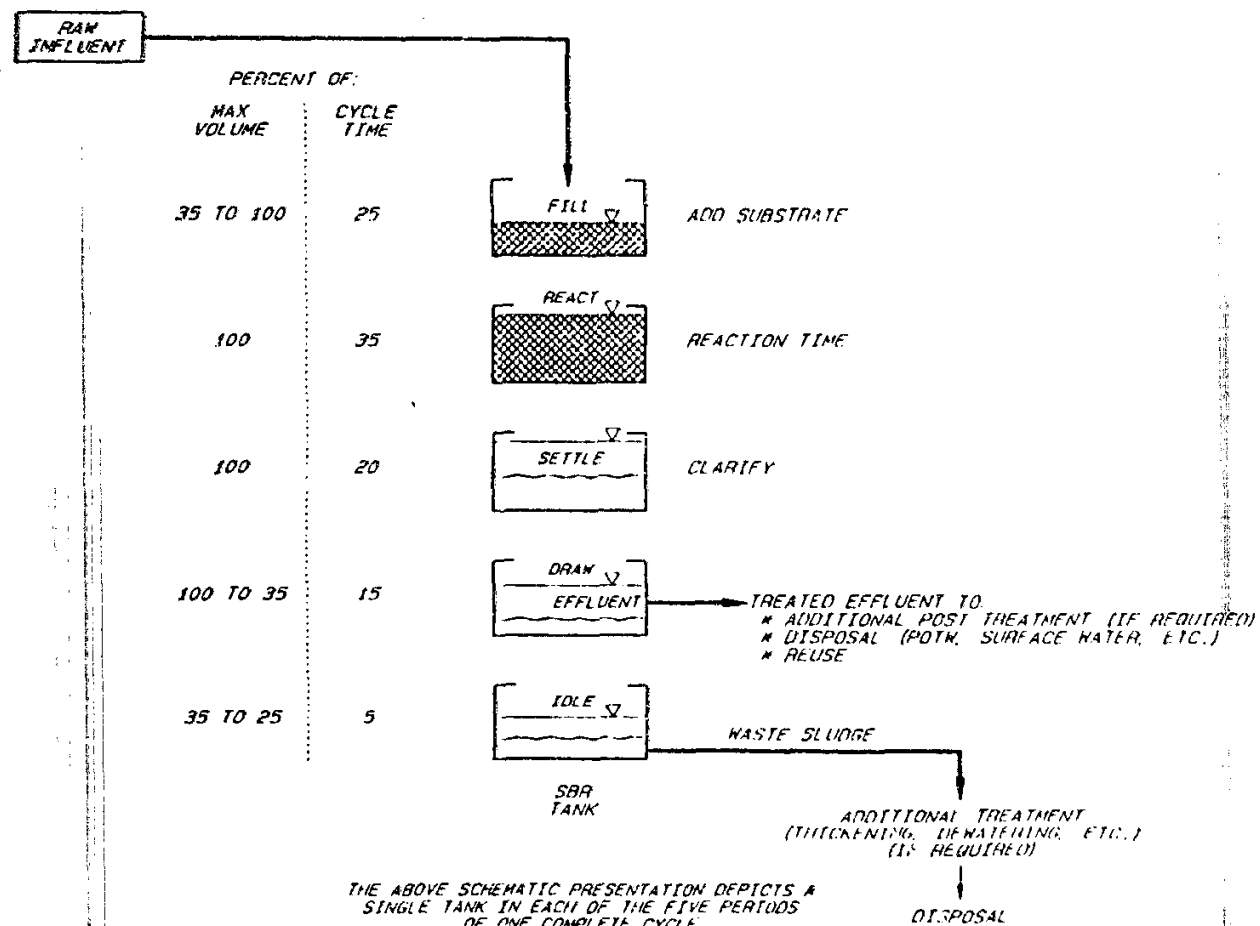
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Ex Situ Treatment
Sequencing Batch Reactor

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FIGURE 1
SCHEMATIC DIAGRAM OF A SEQUENCING BATCH REACTOR SYSTEM



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biodegradable organics from contaminated ground waters. Specifically, the SBR process has been shown to achieve:

- o greater than 99 percent removal of phenolics,
- o between 70 to 95 percent removal of ammonia and
- o between 75 to 95 percent removal of total organic carbon.

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DRAFT

TRICKLING FILTER (Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface water and process wastewaters.

PROCESS TYPE:

Biological Oxidation

RELATED SITE EXPERIENCE:

Wood treating and industrial wastewaters which contain an appreciable concentration of soluble biodegradable organics.

APPLICABLE CHEMICALS OF INTEREST:

Conventional pollutants, phenolics, polynuclear aromatic hydrocarbons (PAH), biodegradable inorganics, polychlorinated biphenyls (PCB) and dioxins/furans.

TECHNOLOGY STATUS:

Established technology for the treatment of domestic and certain industrial wastewaters but no related site experience is available on a full-scale basis. Bench-scale, pilot-scale, full-scale.

DESCRIPTION:

The trickling filter process is an aerobic biological treatment process which is usually used to remove soluble organic compounds found in wastewaters. Trickling filters, in some cases, are also used to achieve nitrification (the conversion of nitrogen in the form of ammonia to nitrate). The trickling filter process is based upon the principle in which a biological growth, attached to a non-moving media, converts soluble organics present in the wastewater into carbon dioxide, water and bacterial solids. This system differs from the activated sludge and aeration tank processes in that in the trickling filter process the microorganisms are attached to media fixed within the reactor rather than suspended within a reactor.

Figure 1 shows a general schematic diagram of a trickling filter system. The raw wastewater (influent) may require some pretreatment prior to entering the trickling filter. This pretreatment is typically necessary for the removal of easily settleable solids or other suspended matter such as free oils or tars. Removal of these materials is necessary so that the filter does not become plugged with solids or become coated with an oil layer, thus reducing the filter's treatment performance.

The influent is sent to the trickling filter and is applied to

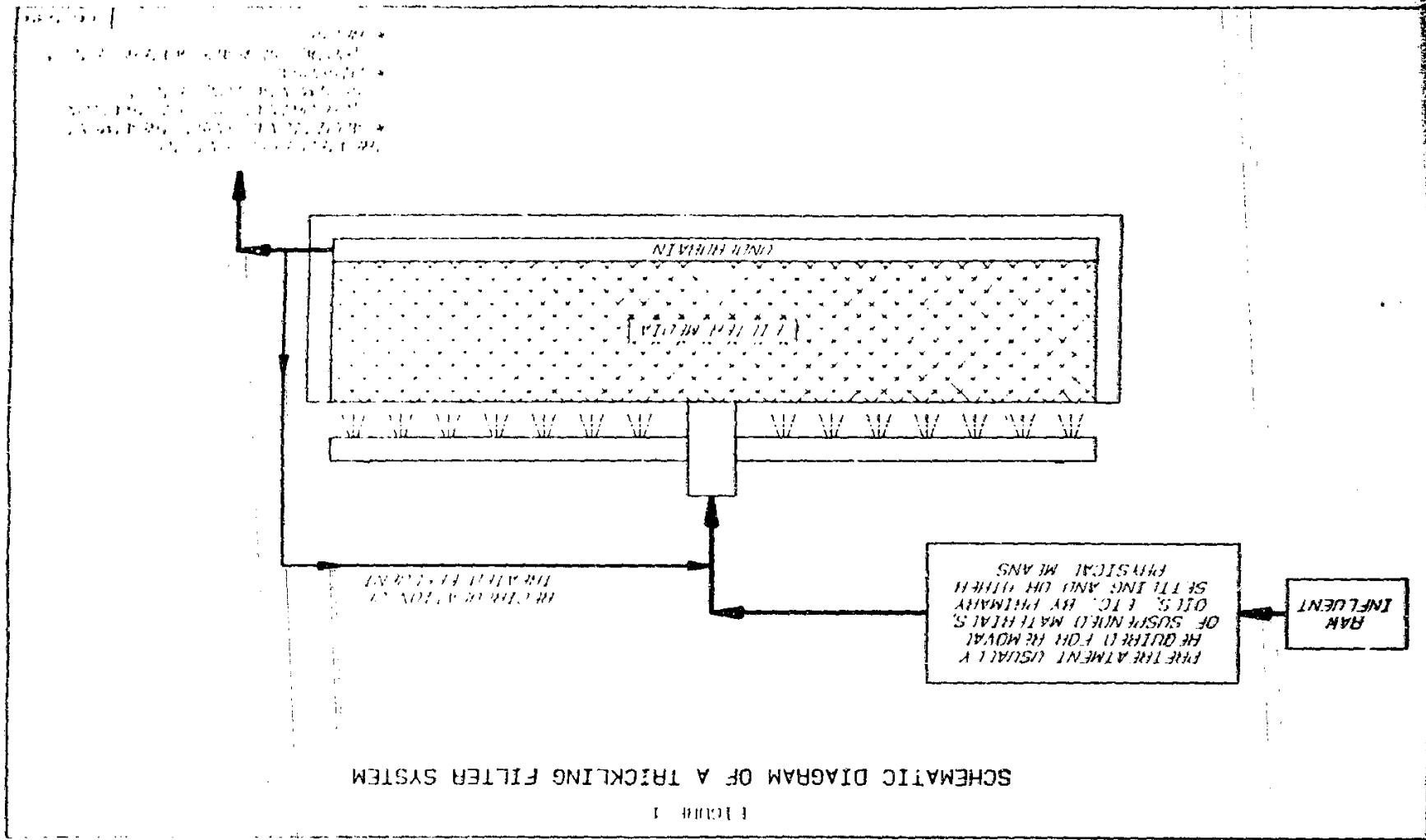
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Ex Situ Treatment
Trickling Filter

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the filter media by means of a water distribution system which allows the wastewater to be uniformly distributed over the media. The wastewater then passes through the filter media where the soluble organics and suspended matter are absorbed and assimilated by the microorganisms which are attached to the media. The ideal media is a material that has a high surface area, is low in cost, has high durability and does not clog easily. In some cases, recirculation water (treated effluent) is recycled to the head of the system where it is joined by the influent.

After the wastewater passes through the filter it is collected in an underdrain system. The underdrain system collects the treated effluent and any solids which have sloughed off of the media. The treated effluent is then ready for discharge with a portion of the effluent recirculated back to the head of the system. Discharge options for trickling filter effluents include discharge to: (i) surface waters (NPDES), (ii) municipal sewers (POTW) and (iii) reuse or polishing treatment.

PERFORMANCE:

Trickling filter treatment is a proven technology for the removal of biodegradable organics from domestic wastewater and has been proven on a pilot-scale basis for wastewaters contaminated with coal tar based chemicals. While a trickling filter unit can be designed and operated to achieve different effluent requirements, the data presented in Table 1 gives results of pilot-scale work examining the treatment of process wastewater from a wood treating operations. In general, these results indicate that a trickling filter process can achieve greater than 99 percent removal of phenolics and most polynuclear aromatic hydrocarbons and greater than 80 percent reduction in total organic carbon content. It should be noted that the efficient operation of a trickling filter can be accomplished only for wastewater streams that contain an amount of soluble organic which are adequate to support a viable mass of microorganisms.

TABLE 1

**TRICKLING FILTER TREATMENT
PILOT-SCALE PERFORMANCE HIGHLIGHTS**

<u>Parameter</u>	<u>Influent</u>	<u>Effluent</u>	<u>Percent Removal</u>
<u>Phenolics</u>			
Phenol, ug/l	33000	< 10	< 99.9
Phenolics - (4AAP)	93	0.06	99.9
2-methylphenol, ug/l	16000	< 10	< 99.9
4-methylphenol, ug/l	36000	33	99.9
<u>Polynuclear Aromatic Hydrocarbons, ug/l</u>			
Acenaphthylene	29	0.198	99.3
Acenaphthene	83	0.434	82.6
Fluorene	73	0.348	99.5
Phenanthrene	72	0.445	99.4
Anthracene	20.6	0.043	99.7
Fluoranthene	57.8	0.809	98.6
Pyrene	35.1	0.623	98.2
Benzo (a)anthracene	9.7	0.144	98.5
Chrysene	7.8	0.137	98.2
Benzo (b)fluoranthene	2.8	0.085	96.9
Benzo (k)fluoranthene	1.97	0.046	97.7
Benzo (a)pyrene	2.87	0.071	97.5
Dibenz (ah)anthracene	0.17	0.005	97.1
Benzo (g,h,i)perylene	1.0	0.037	96.3
Indeno (123-cd)perylene	0.8	0.035	95.6
Naphthalene	2833	1.216	99.9
<u>Conventional Pollutants</u>			
Oil and Grease	34	14	58.8
Total Organic Carbon	337	60	82.2
Total Dissolved Solids	537	393	26.8

Note: All values are expressed in mg/L unless otherwise noted.

AIR STRIPPING
(Ex Situ Treatment)

MEDIUM: Contaminated pumped groundwater, segregated surface waters and process wastewaters.

PROCESS TYPE: Physical separation

RELATED SITE EXPERIENCE: Petroleum industry

APPLICABLE CHEMICALS OF INTEREST: Volatile organics, most polynuclear aromatic hydrocarbons, ammonia and hydrogen sulfide.

TECHNOLOGY STATUS: Established technology for removing volatile organics and ammonia from industrial wastewater. Bench-scale, pilot-scale, full-scale.

DESCRIPTION:

Air stripping technology as applied to contaminated water involves the transfer of volatile compounds from the aqueous phase to the gas phase by passing air (or inert gas) through the mixture. The efficiency of separating volatile compounds is based on the equilibrium partitioning of the compound between water and air and mass transfer rates of the compound within the aqueous phase, across the gas-liquid interface and within the gas phase. The partitioning of a dissolved compound from water to air is a function of solubility, vapor pressure and molecular weight.

A typical flow diagram for an air stripping process using a continuous countercurrent packed column is presented in Figure 1. The packed column is most commonly used for large volumes of water, difficult separations and where high treatment efficiencies are required. Water flows uniformly across the surfaces of the packing providing a high degree of contact with the rising air stream.

Contaminated water can be pumped to holding tanks to help provide a relatively uniform flow and feed composition to the air stripping column. Adjustment of pH can be performed when required. If heating is necessary to achieve improved stripping performance, contaminated water will be passed through a steam or electrically heated exchanger before entering the stripping column. Treated water from the bottom of the column will typically be discharged to a treated effluent storage system to allow for monitoring before discharge. Contaminated air from the top of the column will pass through a demister and often be treated in an activated

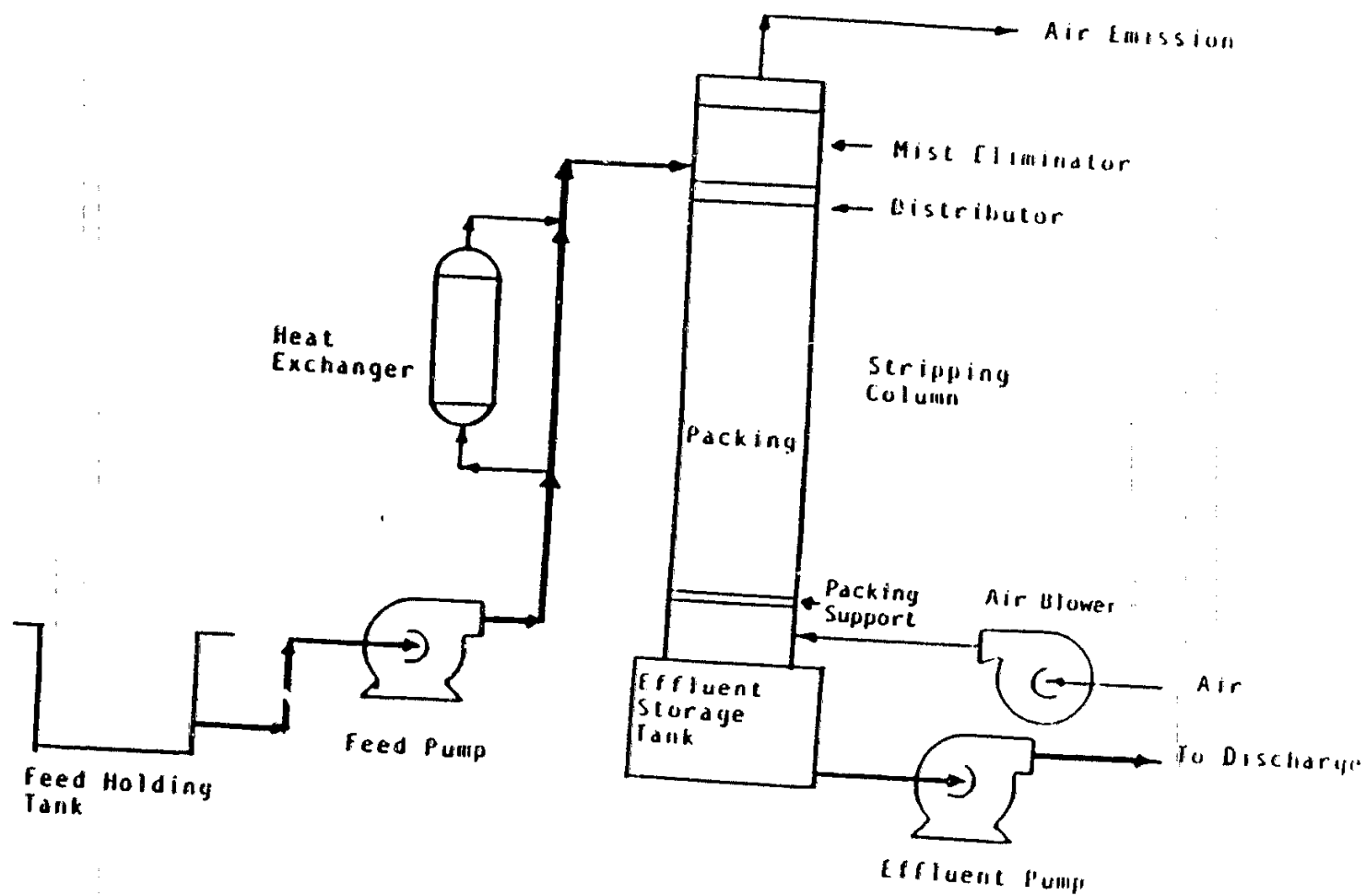
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Ex Situ Treatment
Air Stripping

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PACKED AIR STRIPPING SYSTEM SCHEMATIC



Source: Gas Research Institute, October 1987.

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carbon adsorber before it is discharged to the atmosphere. Contaminated air can also be sent to an existing flare or fume incinerator if such a facility is on site. When the concentration of contaminated air is lower than the regulatory emission limit, the air can be emitted directly to the atmosphere.

A co-current bubble column or countercurrent spray column can be used depending on the volume of water to be treated, the required treatment period, and the type of water to be treated. In a co-current bubble column, air is dispersed into contaminated water by means of a diffuser at the bottom of the column (Figure 2). Mass transfer is a function of bubble size. The water enters at the base of the column and exits the column by means of an overflow weir. This type of stripping system is applicable to contaminated liquid that has a significant amount of suspended solids which might cause fouling. Bubble air stripping can also be used in surface impoundments.

In a countercurrent spray column, water is sprayed into the air by nozzles at the top of the column and is collected in a sump at the bottom. Air enters at the bottom of the column and is directed downward to assure an even flow. Air exits through a demister at the top. Spray columns are the most limited in range of applications due to their limited liquid throughput and turn down potential, and the possibility of their fouling at the nozzles.

Liquid/vapor contactors may be designed to operate with a continuous vapor phase, such as is found in a spray column or packed column, or with a continuous liquid phase such as is found in a bubble column or sparged tank. The contaminated air exhausted from air stripping systems frequently requires treatment before it is discharged to the atmosphere.

PERFORMANCE:

Performance data for bench-scale pilot-scale, and full-scale studies of air stripping related to relevant sites (compounds of interest) are summarized in Table 1. No data has been found for other organic chemicals of interest. Theoretical studies indicate naphthalene should be effectively removed; whereas some PAHs and phenolics may not be applicable.

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TABLE 1

AIR STRIPPING TREATMENT
PERFORMANCE HIGHLIGHTS

Type of Application	Compounds of Interest In Water Treated	Influent Concentration (ppb)	Effluent Concentration (ppb)
Full Scale			
Wausau, WI contaminated well water	Toluene	30.9	0.94
	Ethylbenzene	5.1	0.30
	m,o,p-Xylene	16.6	0.60
Sydney Mine waste site contaminated groundwater	Benzene	11	1(a)
	Ethylbenzene	5	1(a)
	Toluene	10	1(a)
	m,o-Xylene	5	1(a)
	3-(1,1-Dimethylethyl Phenol)	32	10(a)
Florida gasoline contaminated well water	Benzene	45000-	<50
	Toluene	50000	Total
	Xylene	Total	
Bench Scale			
Groundwater treatment	Benzene	5300	<10
	Toluene	3600	<10
API gasoline contaminated groundwater	Benzene	11300	1600
	Toluene	37600	7100
	Ethylbenzene	3200	600
	o-Xylene	5100	1000
	p-Xylene	9500	1700
Pilot Plant			
Groundwater treatment	Benzene	13200	2475
	Ethylbenzene	330	20
	Toluene	13600	2360
	Xylenes	3210	680
Gasoline contaminated household water	Total gasoline compounds	6000-362000	<4

(a) Final effluent from air stripping, multi-media filtering and carbon adsorption processes.

STEAM STRIPPING (Ex Situ Treatment)

<u>MEDIUM:</u>	Contaminated pumped groundwater, segregated surface waters and process wastewaters.
<u>PROCESS TYPE:</u>	Physical separation
<u>RELATED SITE EXPERIENCE:</u>	Chemical industry, coking industry.
<u>APPLICABLE CHEMICALS OF INTEREST:</u>	Volatile organics, most polynuclear aromatic hydrocarbons, PAH, potentially certain phenolics, free ammonia and cyanide, and hydrogen sulfide.
<u>TECHNOLOGY STATUS:</u>	Established technology for removing volatile organics and ammonia from industrial wastewater. Applications to remove organic compounds with high boiling points is less demonstrated. Pilot-scale and full-scale.
<u>DESCRIPTION:</u>	<p>Steam stripping is a distillation separation technique applicable to removing certain organic compounds or dissolved gases from dilute aqueous solutions. The technique depends on the relative volatility of the components being stripped to the volatility of water. Relative volatility, or the ratio of vapor composition to liquid composition for the two components (e.g. water and organic) under consideration, is a function of the activity coefficient and vapor pressure of the compound. If the relative volatility is known for a particular organic contaminant, a determination can easily be made as to the technical and economic viability of using stripping as a treatment method.</p> <p>A typical flow diagram for a steam stripping system is presented in Figure 1. The system will consist primarily of a stripping column containing random dumped packing. The feed may be pretreated by adjusting the pH if necessary and passing through a strainer or filter. To minimize energy consumption and cooling water requirements, the feed can be used as cooling water for the overhead condenser and/or heat exchanged with treated water from the bottom of the column. Further energy savings can be realized by using multiple vapor recompression (MVR) to recover more of the heat contained in the vapor overhead stream. Preheated feed will typically be fed into the top of the stripping column. In some cases, the feed will be introduced at a carefully selected intermediate location along the height</p>

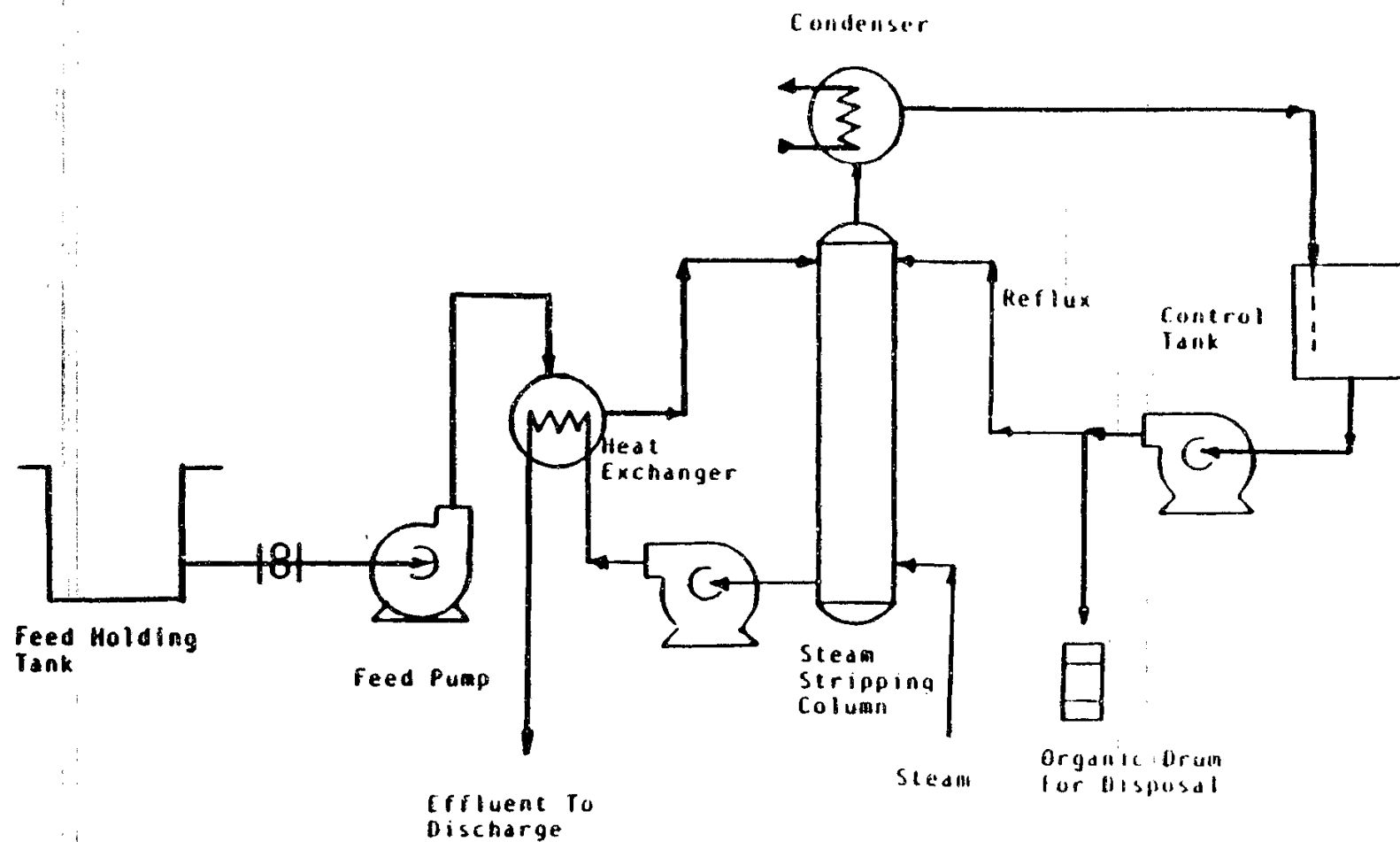
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Ex Situ Treatment
Steam Stripping

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STEAM STRIPPER PROCESS SCHEMATIC

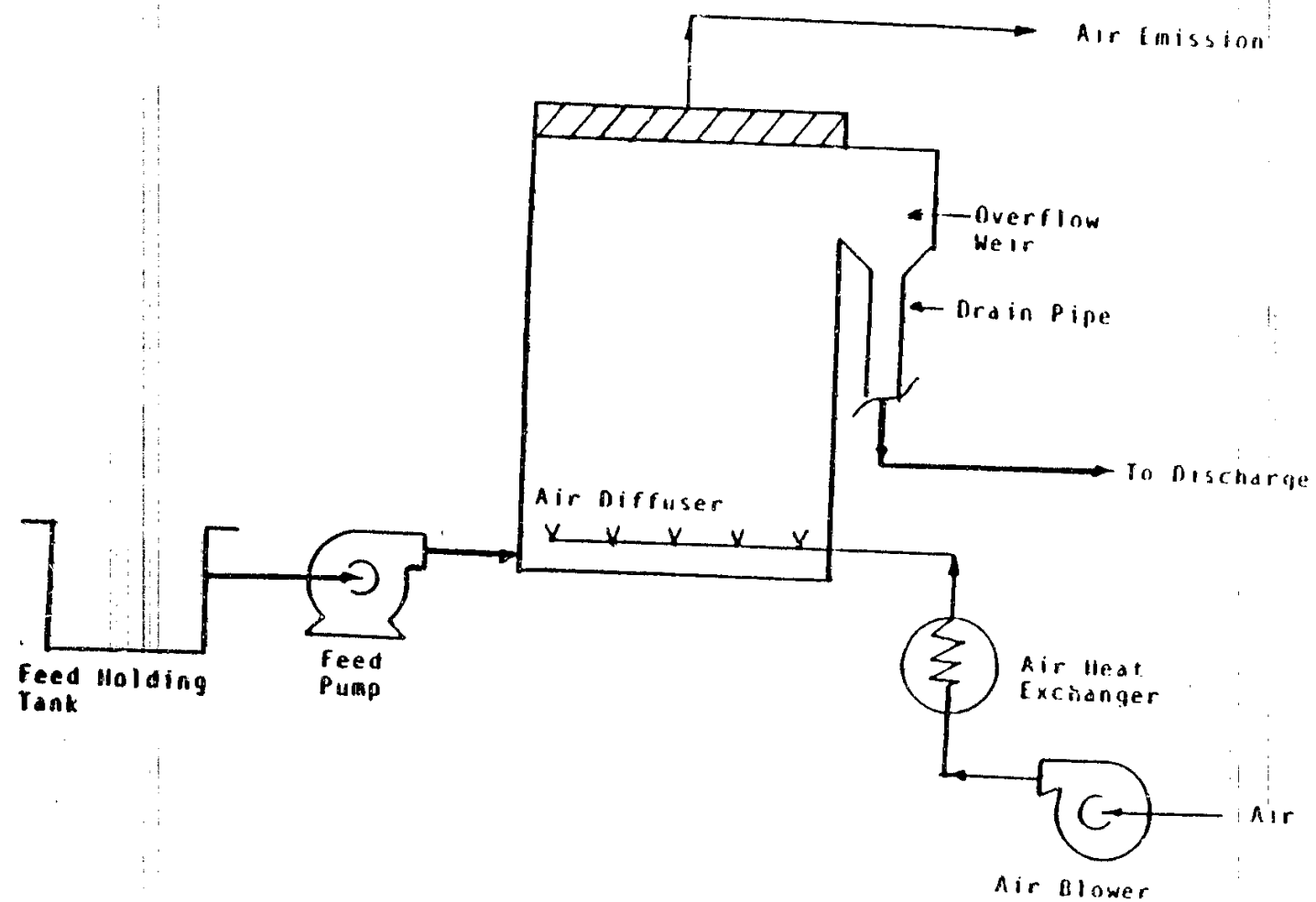


Source: Gas Research Institute, October 1987

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FIGURE 2

BUBBLE AIR STRIPPING SYSTEM SCHEMATIC



Source: Gas Research Institute, October 1987.

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of the column to provide for additional concentration of the organic in the vapor leaving the top, thereby reducing the quantity of distillate that must be treated or disposed of. Distillate from the overhead condenser will flow by gravity to a control tank. If the column includes a rectification section, a portion of condensate is recycled (refluxed) back to the top of the column. If the organic has very low solubility in water, rectification can result in a separation of an organic phase in the distillate receiver. In this case, only the aqueous phase is refluxed and the organic phase is removed for disposal.

PERFORMANCE:

Based on theoretical estimates, levels of 1-10 ppb should be achieved for strippable organics. Pilot-scale data for BTX show levels of 0.5 ppb can be achieved. No full-scale data on organic chemicals of interest are available. Industry (coke plants) data on removal of acid gases (H_2S , HCN) and ammonia at high feed concentrations are available, but not relevant.

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2

**Ex Situ Treatment
Steam Stripping**

BIOFILTRATIONSM
(Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface waters and polishing treatment for process wastewaters.

PROCESS TYPE:

Filtration, adsorption/desorption, and aerobic biological oxidation.

RELATED SITE EXPERIENCE:

Wood treating industry and coal tar distillation industry.

APPLICABLE CHEMICALS OF INTEREST:

Conventional pollutants, phenolics, polynuclear aromatic hydrocarbons (PAH), volatile organics, biodegradable inorganics, polychlorinated biphenyls (PCB) and dioxin/furans.

TECHNOLOGY STATUS:

Developing technology, bench-scale, pilot-scale and full-scale.

DESCRIPTION:

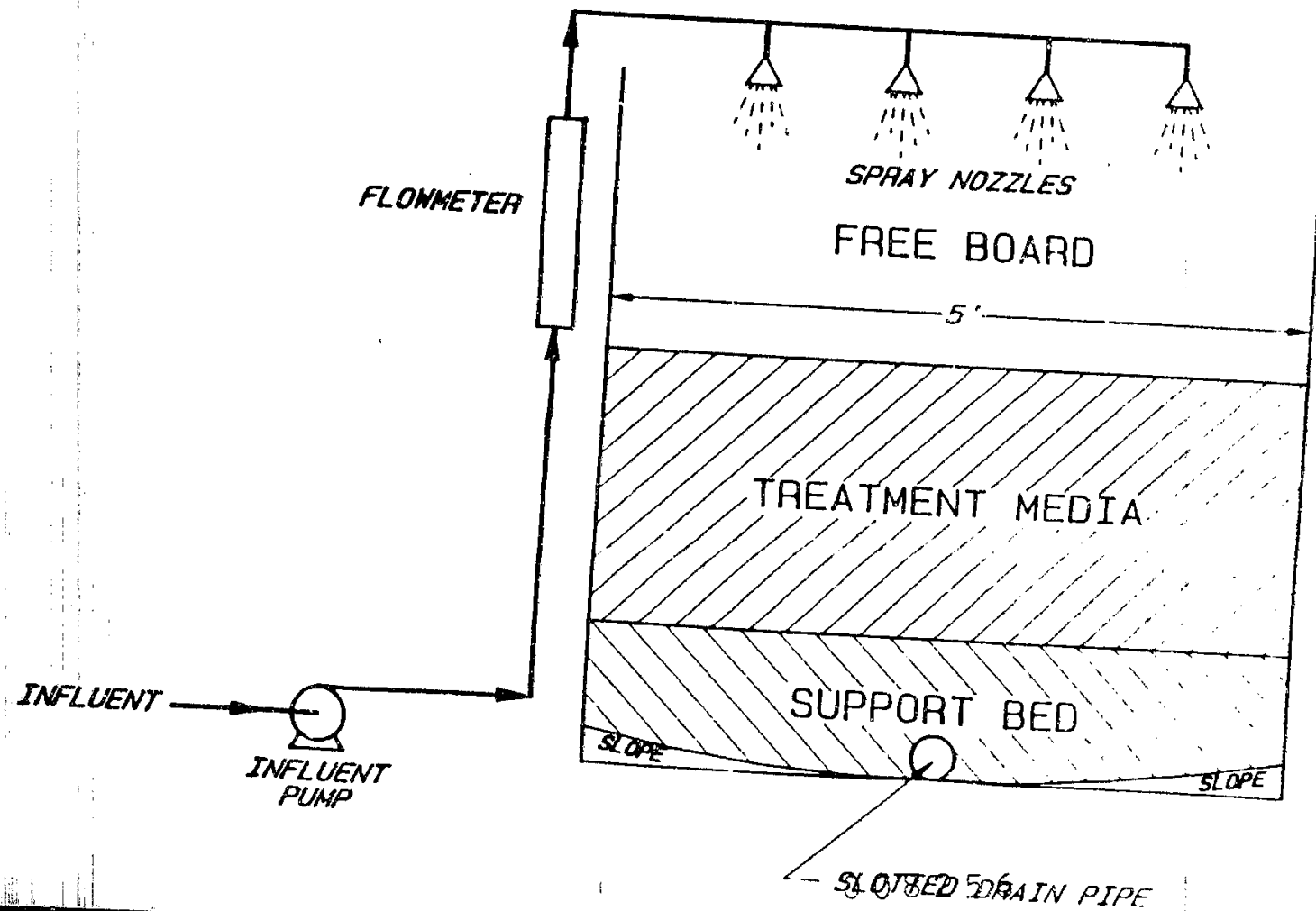
BioFiltrationSM is a proprietary process developed by Keystone Environmental Resources, Inc. for the treatment of slightly contaminated pumped groundwaters and polishing treatment of process wastewaters. In general, it is an unit process for treatment of aqueous liquids which combines the treatment capabilities of filtration, adsorption and biodegradation into a single process.

A BioFiltrationSM treatment unit filters suspended solids and adsorbs organic constituents onto a bed of selected matrix materials which are simultaneously biologically regenerated. The composition of the treatment media is dependent upon the particular effluent stream to be treated and is designed to provide the appropriate combination of permeability and adsorption capacity.

As illustrated in Figure 1, effluent requiring treatment is applied to the top of the bed where suspended particulates are filtered out at the surface. Soluble organics are adsorbed as the media water percolates down through the treatment media. Concurrently, the media which contains an acclimated microbial population, continually regenerates the adsorbent material in the treatment media. The resulting treated effluent is collected in an underdrain system and then

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FIGURE 1
SCHEMATIC CROSS-SECTION OF BioFILTRATIONSM TREATMENT PROCESS



discharged.

PERFORMANCE:

Through extensive bench and pilot-scale testing, Keystone has demonstrated that BioFiltrationSM is a proven technology for removal of adsorbable and biodegradable chemicals from water and wastewater effluents. While a BioFiltrationSM treatment unit can be designed and operated to achieve different effluent requirements, the data given in Table 1 presents results of pilot-scale testing where process wastewater cresote/pentachlorophenol from a wood treating plant was treated after biological lagoon treatment.

As evidenced by the data presented, BioFiltrationSM treatment offers a very viable polishing treatment technology. Through pilot-scale work evaluating polishing treatment of aeration tank biologically treated process wastewater from a creosote/pentachlorophenol wood treating plant, BioFiltrationSM treatment produced an effluent in which 100 percent fish survival was achieved in 7-day weight gain fish toxicity testing.

008257

TABLE 1

KEYSTONE'S BIOFILTRATIONSM TREATMENT
PERFORMANCE HIGHLIGHTS

<u>PARAMETER</u>	<u>INFLUENT</u>	<u>EFFLUENT</u>	<u>% REMOVAL</u>
BOD ₅ (mg/l)	99	3	96.9
TOC (mg/l)	518	9	98.3
PENTACHLOROPHENOL (mg/l)	10.6	< 0.001	> 99.9
PHENOLS (4-AAP) (mg/l)	0.65	< 0.01	> 98.5
TOTAL PAH (mg/l)	0.09	< 0.0012	> 98.7
TOTAL DIOXINS (ng/l)	24,600	< 1.0	> 99.9

Note: < values indicates detectable concentrations.

008258

CARBON ADSORPTION
(Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwater, segregated surface waters and process wastewaters.

PROCESS TYPE:

Physical separation

**RELATED
COKE/COAL TAR
SITE EXPERIENCE:**

Petroleum industry, wood treating sites, coking and coal tar distillation sites, chemical plants and other industries.

**APPLICABLE
CHEMICALS OF
INTEREST:**

All soluble organic chemicals of interest, potentially effective for certain metals and cyanide compounds.

**TECHNOLOGY
STATUS:**

Established technology for removing soluble organics from wastewaters. Bench-scale, pilot-scale, full scale.

DESCRIPTION:

In adsorption processes, selected dissolved contaminants are attracted to and adhere to a solid adsorbent as a result of weak chemical bonds between the contaminant and "active sites" on the surface of the adsorbent. Activated carbon is a highly porous solid which provides and extremely large "active" surface area. For aqueous treatment, the primary driving forces for adsorption are a combination of the hydrophobic nature of the contaminant and the affinity of the contaminant for the carbon. The adsorption of a specific chemical will depend on the carbon properties, the physical and chemical characteristics and the concentration of the contaminant, the characteristics of the aqueous phase, and the residence or contact time.

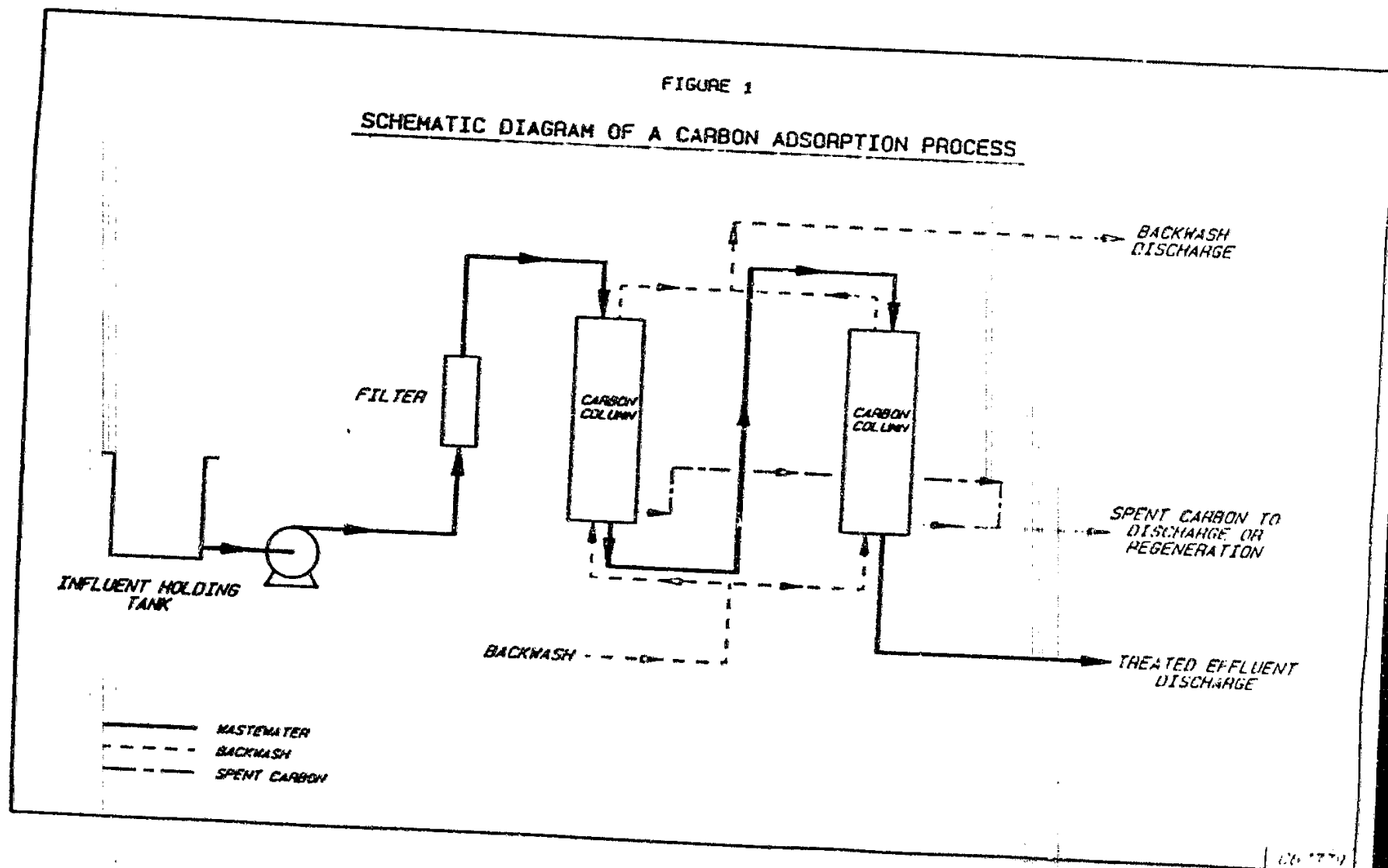
A typical flow diagram for a carbon adsorption process is presented in Figure 1. Contaminated water can be pumped to holding tanks to help provide a feed with a relatively uniform and composition. The feed is then pumped continuously through a filter to the carbon adsorbers. The dual bed series system shown offers a simple valving arrangement, a flexible carbon bed changing schedule and a high effluent quality. As shown in Figure 1, the two columns are operated in a lead-polish mode to enable the lead column to achieve maximum loading of contaminants (minimum carbon consumption). Heavy lines indicate normal flow pattern. When the lead column is exhausted (as determined from monitoring the effluent for selected pollutants), it is taken off line, the backup column becomes the lead column, and the carbon is replaced or regenerated. This

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**Ex Situ Treatment
Carbon Adsorption**

008259



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column then becomes the second column in the series. Figure 1 does not include the flows required if in situ regeneration is used.

Treated water from the adsorbers is typically discharged directly unless a treated effluent storage system is needed to allow for monitoring before discharge. A more cost effective approach than temporarily storing and monitoring the effluent prior to discharge is to monitor the discharge from the lead column on a regular basis and rely on the fact that the polishing column will maintain desired effluent quality.

Carbon adsorption has been used at many hazardous waste sites for treating ground water or surface water with contaminated with chemicals of interest. Performance of bench-scale, pilot-plant, and full-scale carbon adsorption systems related to relevant sites is summarized in Table 1.

PERFORMANCE:

In addition to the examples presented in Table 1, carbon adsorption is being used for treating contaminated ground water at a MGP site in California. The system, which has flocculation/sedimentation and sand filtration pretreatment steps, operated about one year prior to the first carbon replacement. Performance data have been obtained every three months by analyzing the final effluent for PAHs, benzene, toluene, xylene and other volatile hydrocarbons; lead was also analyzed on the first two sampling campaigns. PAH levels were reduced from 3.4 to 0.39 ppm to non-detectable concentrations. Aromatics, which were detected in only half the ground water samples, were reduced from nearly 20 ppm to non-detectable concentrations. However, the specific contribution of the carbon adsorbers in achieving the overall removals cannot be determined since samples of adsorber influent were not taken.

008261

**TABLE 1
CARBON ADSORPTION TREATMENT PERFORMANCE HIGHLIGHTS**

Type of Application	Compounds of Interest	Influent Concentration (ppb)	Effluent Concentration (ppb)	Liquid Flow Rate (gpm)	Hydraulic Loading (gpm/sq ft)	Carbon Consumption Rate <u>lb Carbon</u> 1000 gal
Full Scale						
Gasoline contaminated groundwater	Benzene	150	1	150	3	NA
	Toluene	150	1			
	Xylene	150	1			
Creosote contaminated groundwater	PAH (Total)	200-500	1	50	2	NA
Rail car spill contaminated	Phenol	32000-40000	< 100	NA	22	2.1
	Phenol	63000	< 1	80	1.0	NA
Contaminated groundwater	Benzene	5000	< 10	100	1.3	1.1
Chemical spill contaminated groundwater	Benzene	400	< 1	95	1.21	
On-site storage tank contaminated groundwater	Xylenes	200-500	< 1	30	2.4	NA
	Xylenes	8000	< 1	200	2.5	NA

NOTE: NA indicates not available.

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TABLE 1 (CONTINUED)
CARBON ADSORPTION TREATMENT PERFORMANCE HIGHLIGHTS

Type of Application	Compounds of Interest	Influent Concentration (ppb)	Effluent Concentration (ppb)	Liquid Flow Rate (gpm)	Hydraulic Loading (gpm/sq ft)	Carbon Consumption Rate lb Carbon 1000 gal
Gasoline spill contaminated groundwater	Benzene Toluene Xylenes	900-11000 5000-7000 6000-10000	< 100 Total	5 NA	0.4 NA	NA NA
Wausau gasoline station contaminated groundwater	Benzene Toluene Ethylbenzene Xylene	180-230 17-190 16-20 63-100	< 1 < 1 < 1 < 1			
Upstate New York gasoline contaminated well water	Benzene Toluene Xylenes	55 85 52	< 1 < 1 < 1	5	9.2	NA
Lower Mississippi River contaminated drinking water	Benzene Toluene PAHs(each)	0.010	0.00002 0.00002 0.002	278 410	0.73 1.07	NA NA
Love Canal landfill leachate	Benzene Ethylbenzene Toluene Phenol Anthracene & Phenanthrene	28,000 590 25,000 2,400 29	< 10 < 10 < 10 < 10 Non Detectable	max 175	NA	NA
<u>Pilot Plant</u>						
Contaminated groundwater	Benzene Ethylbenzene Toluene Xylenes	2475 20 2360 680	< 1.0 1.0 1.0 < 1.0	3-5	1-1.6	NA

NOTE: NA indicates not available

008263

TABLE 1 (CONTINUED)
CARBON ADSORPTION TREATMENT PERFORMANCE HIGHLIGHTS

Type of Application	Compounds of Interest	Influent Concentration (ppb)	Effluent Concentration (ppb)	Liquid Flow Rate (gpm)	Hydraulic Loading (gpm/sq ft)	Carbon Consumption Rate <u>lb Carbon</u> 1000 gal
Gasoline contaminated household water	Benzene	1000	< 5	NA	NA	NA
	Toluene	Total	< 5	NA	NA	NA
	Xylenes		< 5			
	Benzene	25000	< 5	NA	NA	NA
	Toluene	Total	< 5			
	Xylenes		< 5			
<u>Bench Scale</u>						
API Gasoline contaminated groundwater	Benzene	17849	10.4	NA	7	NA
	Ethylbenzene	3323	3.57			
	O-Xylene	5656	15.0			
	P-Xylene	11422	15.0			
	Toluene	57537	1.73			

NOTE: NA indicates not available.

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CHEMICAL OXIDATION (Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwater, segregated surface waters and process wastewaters.

PROCESS TYPE:

Chemical oxidation using either chlorine (Cl_2), chlorine dioxide (ClO_2), hydrogen peroxide (H_2O_2), or ozone (O_3).

RELATED SITE EXPERIENCE:

Chemical industry, wood treating industry, manufactured gas plant sites, municipal wastewater treatment plants, and the coke and coal tar distillation industry.

APPLICABLE CHEMICALS OF INTEREST:

Ammonia, cyanide, sulfide, thiocyanate, volatile organics, phenolics, reduced metals, polynuclear aromatic hydrocarbons (PAH) and conventional organic pollutant indicators (BOD_5 , COD, TOC).

TECHNOLOGY STATUS:

Established technology in the United States with regard to chlorination with Cl_2 . Ozone (O_3) and H_2O_2 are beginning to obtain market exposure. Bench-scale, pilot-scale, full-scale.

DESCRIPTION:

Chemical oxidation is a process in which the oxidation state of a chemical contaminant(s) are increased via the release of electrons from the contaminant(s) which are accepted by a chemical oxidant in solution. Through this process, targeted chemical contaminants are converted to chemical species which are neither harmful nor otherwise objectionable. The specific chemical reactions which occur are dependent upon the particular chemical contaminants, the particular chemical oxidant (electron acceptor) and the solution pH.

Oxidants most normally considered include chlorine, chlorine dioxide, hydrogen peroxide and ozone.

The chlorination process utilizes chlorine gas or a salt of hypochlorous acid such as calcium hypochlorite or sodium hypochlorite as the chlorine source. The active species is the same regardless of the parent chemical, but the properties of the aqueous chlorine solution will vary with the different chemicals. Thus, it is sometimes more appropriate to use one source of chlorine over another depending on site specific conditions. Currently, the primary use of chlorination is for disinfection, but it is also widely used for many other

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Ex Situ Treatment
Chemical Oxidation

008265

applications including the destruction of specific harmful chemicals. The knowledge of the fundamental chemistry of chlorination has been enlarged considerably in the past twenty-five years; this has made it possible to apply chlorination to the treatment of an ever increasing variety of industrial wastewaters.

Chlorine dioxide in the gaseous form is highly unstable and therefore aqueous solutions of the gas are utilized in oxidation processes. Although these solutions are much more stable than the gaseous form, they still decompose rapidly and thus are generated on-site.

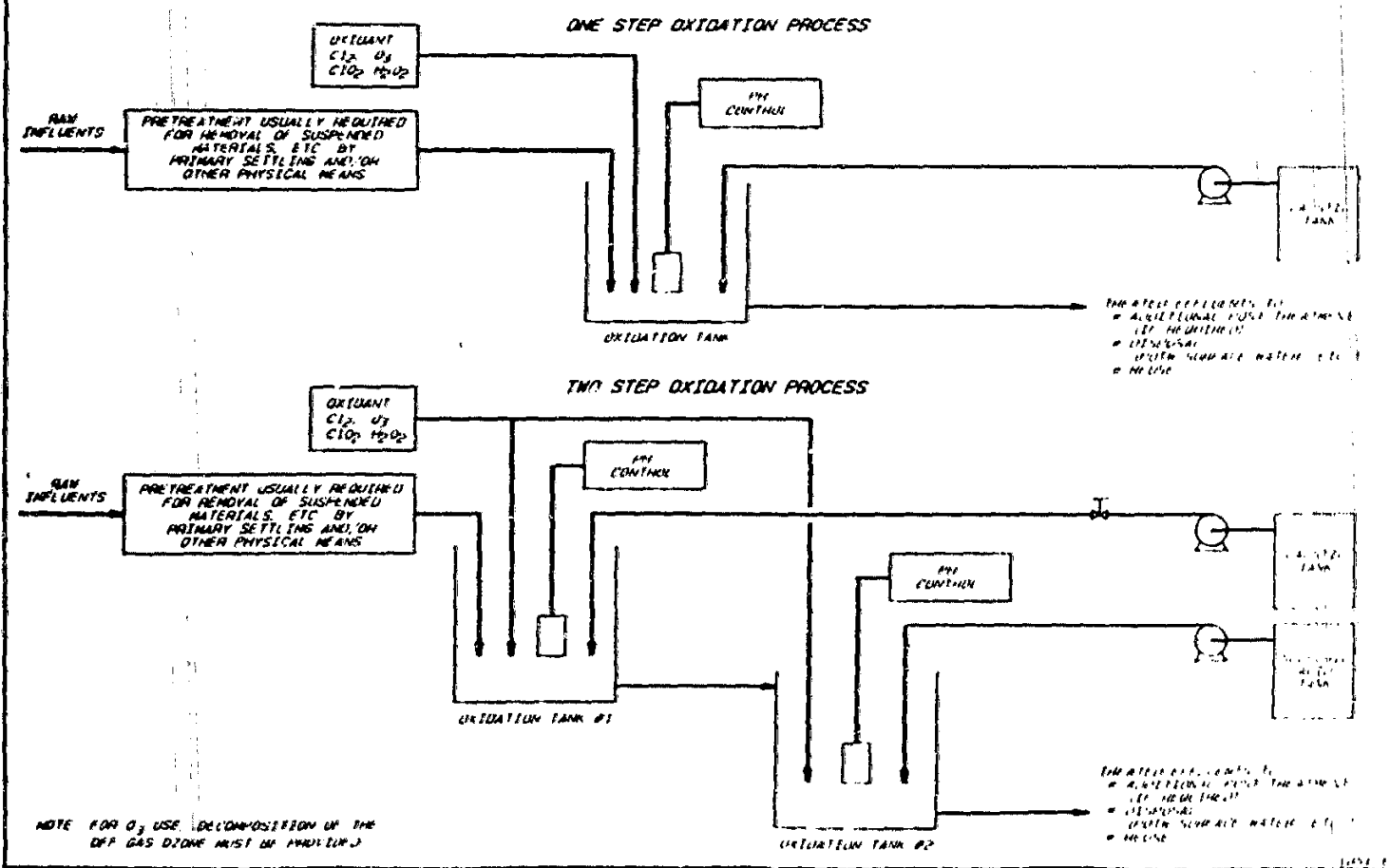
Hydrogen peroxide is also utilized as an aqueous solution for chemical oxidation. A 35 percent solution is available commercially. This solution is used full-strength or diluted, depending on the specific oxidation application. Metal catalysts are most often used with hydrogen peroxide treatment.

Ozone is cited by some researchers as being the second-most powerful oxidant, exceeded in its oxidation potential only by fluorine. The effectiveness of ozone in oxidizing organic compounds in water is well documented. Ozone has been used in Europe since 1903 for the treatment of drinking water. Ozone is an unstable compound and must be generated on-site. For commercial applications, ozone is produced through the discharge of an electric current across an air stream containing oxygen. The ozone enriched gas stream is contacted with the water targeted for treatment in a reaction vessel.

Figure 1 presents two possible treatment schemes for chemical oxidation. A one-step process is depicted in the upper portion of the drawing and a two-step process in the bottom portion. Oxidation of certain wastewater, e.g. ammonia containing, can be accomplished in one step with oxidant addition and pH adjustment in one reaction tank. Some wastewaters, e.g. cyanide containing, must be treated using a two-step process in which an oxidant and caustic soda are added to the first tank for initial oxidation at a high pH and then an oxidant and sulfuric acid are added to the second tank for further oxidation at a lower pH. The retention time in the reaction tank(s) and the dosage(s) of oxidant used also vary with the composition of the wastewater. Theoretical considerations and treatability results are used to establish the process, specific oxidant(s), oxidant dosage(s) and retention times(s) needed to properly treat a specific wastewater.

In general, different oxidants require different preparation systems. Chlorine gas or a salt of

FIGURE 1
SCHEMATIC DIAGRAM OF
CHEMICAL OXIDATION WITH Cl_2 , ClO_2 , H_2O_2 , OR O_3



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hypochlorous acid, e.g. sodium hypochlorite calcium hypochlorite, can be used for chlorination. These chemicals are obtained in bulk and metered directly into the reaction tank. Hydrogen peroxide is also obtained in bulk and metered directly into the reaction tank. Because of their poor stability, chlorine dioxide and ozone must be generated on-site. Chlorine dioxide is synthesized using hypochlorous acid, sodium chlorite and hydrochloric acid. Ozone is added as a gas with provisions for decomposition of the off gas provided. Chemical oxidation is used for pretreatment, primary treatment, or post treatment depending on the composition of the wastewater and the desired effluent quality. For many of these applications it is necessary to remove the excess oxidant, e.g. dechlorinate, before further treatment or disposal of the wastewater.

PERFORMANCE:

Chemical oxidation is a proven technology for removal of oxidizable contaminants from domestic wastewaters and groundwaters/surface waters. The three chemical oxidation processes considered here are (i) chlorination, (ii) chlorine dioxide, (iii) hydrogen peroxide and (iv) ozone oxidation. The contaminant removals that can generally be achieved with a properly designed and operated chemical oxidation treatment system are as follows for each of the above processes:

Chlorination:

- o Greater than 96 percent removal of ammonia,
- o Greater than 99 percent removal of cyanide,
- o Between 14 and 21 percent removal of volatile organics,
- o Greater than 99 percent removal of phenolics,
- o Between 10 and 75 percent removal of polynuclear aromatic hydrocarbons,
- o Between 45 and 50 percent removal of total organic carbon and
- o Anticipated oxidation of sulfides and thiocyanates from literature information.

Chlorine Dioxide Oxidation:

- o Between 95 and 99+ percent removal of phenolics,
- o Between 85 and 99+ percent removal of sulfides,

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- o Greater than 99 percent removal of polynuclear aromatic hydrocarbons and naphthalene,
- o Between 90 and 99+ percent removal of volatile organics and
- o Anticipated oxidation of cyanide from literature information.

Hydrogen Peroxide and Ozone Oxidation:

- o Greater than 99 percent removal of cyanide,
- o Between 50 and 99+ percent removal of phenolics,
- o Between 5 and 99+ percent removal of polynuclear aromatic hydrocarbons and
- o Anticipated oxidation of sulfides, thiocyanates and total organic carbon from literature information.

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DISSOLVED AIR FLOTATION (Ex Situ Treatment)

<u>MEDIUM:</u>	Contaminated pumped groundwaters, segregated surface waters and process wastewaters.
<u>PROCESS TYPE:</u>	Physical liquid/solids separation.
<u>RELATED SITE EXPERIENCE:</u>	Petroleum industry, wood treating sites, coal tar distillation sites and other industries.
<u>APPLICABLE CHEMICALS OF INTEREST:</u>	Oil and grease, polynuclear aromatic hydrocarbons (PAH/Naphthalene).
<u>TECHNOLOGY STATUS:</u>	Established technology for the removal of oil and grease and suspended solids. Bench-scale, pilot-scale, full-scale.
<u>DESCRIPTION:</u>	<p>Dissolved air flotation (DAF), to some extent, is the reverse of gravity oil/water separation. The DAF process is generally used on waste streams where the specific gravity of the material to be separated is very close to that of water. These particles settle very slowly or not at all. It is much easier to float and remove them from the water surface than to attempt to sink them.</p> <p>The basic principle involved with the DAF process is the fact that as the pressure increases on water, it is able to contain more dissolved air, nitrogen, or other gas. When this pressure is reduced, the gas is released as extremely fine bubbles. This can be achieved in two different ways. The first and most common method is by pressurizing the water then releasing it to the atmosphere in the flotation tank (pressure flotation). The other method is less common but produces the same results and involves decreasing the pressure in the flotation unit by drawing a vacuum. The air naturally dissolves in the water and is released when the pressure decreases.</p> <p>Three variation of pressure flotation exist: direct, partial and recycle. The direct DAF process requires that the material to be separated can withstand the high shear forces of the pressurizing pump and the pressure release valve. This method is generally used for separating oil from wastewater streams. Partial DAF reduces pumping cost but generally is not as efficient for high oil loadings. Effluent recycle is the most common method of dissolved air flotation. It is used when the material to</p>

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Ex Situ Treatment
Dissolved Air Flotation

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be removed forms a fragile floc. This is generally the case when coagulants and flocculants are used to enhance separation.

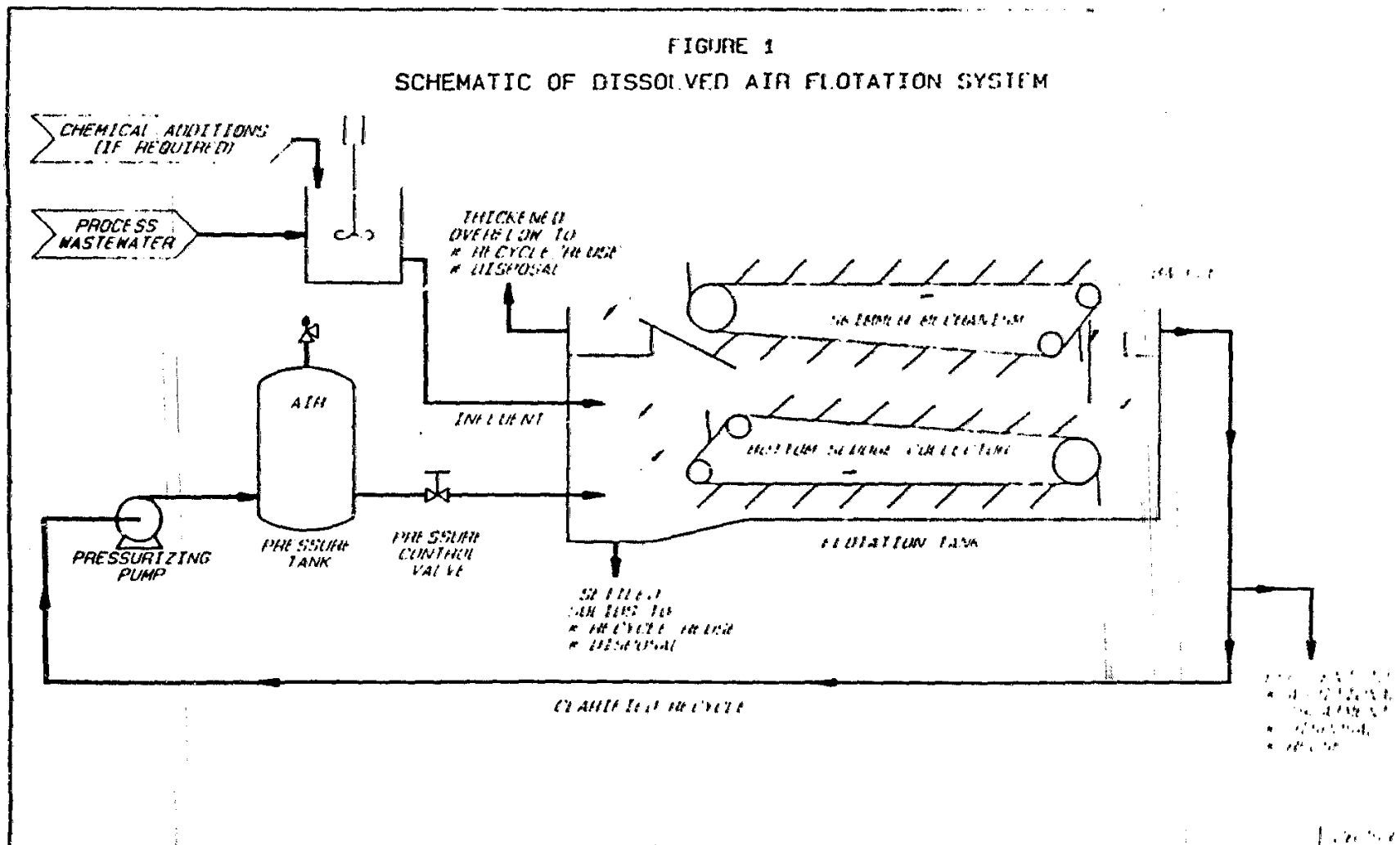
Given in Figure 1 is a schematic diagram of a effluent recycle DAF process. The wastewater, pretreated with coagulants/flocculants, enters the flotation tank with the pressurized recycle. The escaping air bubbles attach to the flocculated material and rise to the surface and compact. The heavy solids that sink are removed from the bottom of the tank and are recycled/reused or disposed. The surface skimmings are also removed and recycled/reused or disposed. The clarified effluent is removed from below the surface and is discharged, reused, or receives additional treatment. A portion of the clarified effluent is recycled and pressurized to be reused in the DAF process.

PERFORMANCE:

Dissolved air flotation is a viable treatment alternative for the removal of oil and grease and suspended solids. Removal of other pollutants is related more to the wastewater characteristics than to the design of the DAF unit. Economics and the space available will be the major factors of concern for the selection of DAF as a treatment alternative. A properly designed and operated unit can generally achieve:

- o Greater than 90 percent removal of oil and grease,
- o Total PAH reduction near 90 percent and
- o Naphthalene reduction near 50 percent.

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EVAPORATION (Ex Situ Treatment)

MEDIUM:

Water containing solids and dissolved organics.

PROCESS TYPE:

Physical separation

RELATED SITE EXPERIENCE:

Petroleum industry, electric-utility sites, wood treating sites, coal tar distillation industry, and chemical plants.

APPLICABLE CHEMICALS OF INTEREST:

For aqueous mixtures, evaporation is applicable to all chemicals of interest. However, the volatilization of strippable compounds (e.g. BTX and most PAHs) may require treatment of the evaporated water prior to discharge. For tars, evaporation is applicable to removing BTX and phenolics which have lower boiling points.

TECHNOLOGY STATUS:

Established technology for the concentration of waste streams. Bench-scale, pilot-scale, full-scale.

DESCRIPTION:

Evaporation is the process of removal of volatile constituents from a solution or slurry by boiling. It can be used to concentrate an aqueous waste solution, separating the major portion of water from the nonvolatile components such as solids, dissolved salts, or nonvolatile organics.

Evaporation usually requires that heat be transferred from a heat source such as steam or hot oil through a heat transfer surface to the waste. Heat transfer rates and overall energy efficiency vary with the type of evaporator and the thermal and flow properties of the waste. There are several classifications of evaporators, including tubular or plate evaporators, wiped-film evaporators, direct-contact evaporators and natural energy evaporators. Selection of an evaporator type depends mainly on the feed characteristics, degree of separation or concentration required, and the relative costs of equipment and utilities.

A simplified schematic of an evaporator system is shown in Figure 1. The influent feed is pumped to a feed preheater and then introduced into the top of the evaporator. The evaporator consists of a jacketed cylindrical shell with rotating wiper blades which produce a thin, agitated film. Evaporation of the volatiles takes place as the waste stream flows by gravity down the evaporator wall. Temperature and vacuum

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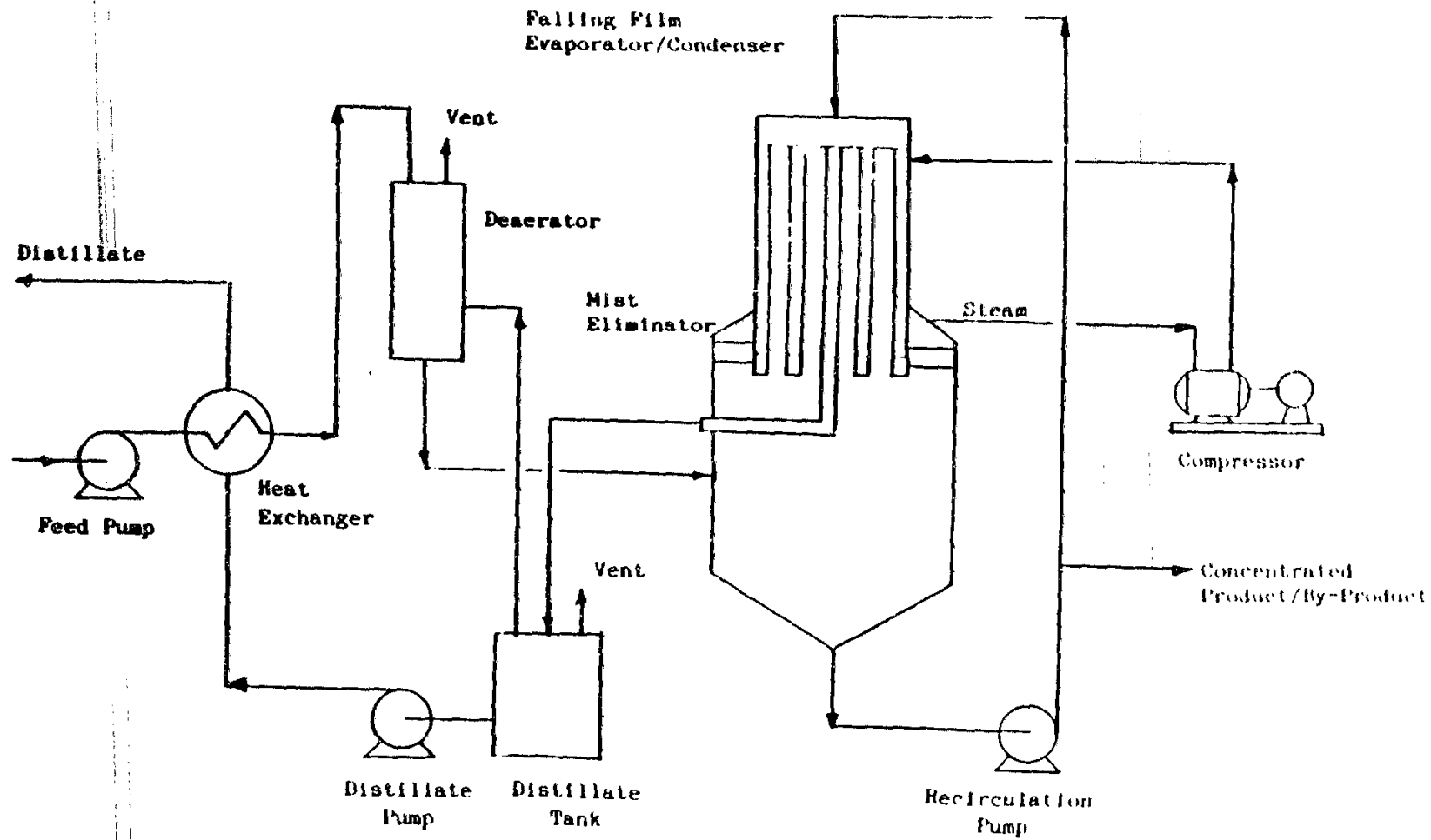
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Ex Situ Treatment
Evaporation

008273

FIGURE 1

HVR FALLING FILM EVAPORATOR SCHEMATIC



Source: Gas Research Institute, October 1987.

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are adjusted to accomplish the desired residual volatile level. The vapor passes through an entrainment separator and is condensed and collected as distillate. A vacuum pump is used to reduce the pressure within the evaporator, thereby increasing the volatilization efficiency. The concentrated residue exits through the bottom section, and can be transferred to a residue cooler (not shown) before being discharged to containers for transport, disposal, or other disposition.

Evaporation can also refer to volatilization processes that do not involve boiling; but in which water or a volatile organic is transferred to the air, as in a drying process. Solar evaporation ponds and cooling towers are common examples of such aqueous evaporation processes. These "open" processes which rely on air flow are not discussed.

PERFORMANCE:

Evaporation has been commercially applied or tested in a wide variety of applications. However, no specific performance data for the compounds-of-interest have been found. Equipment manufacturers consider evaporation to be a potential application or waste streams containing the chemicals of interest unless abrasives are present.

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FILTRATION **(Ex Situ Treatment)**

MEDIUM: Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE: Physical Solids Separation

RELATED SITE EXPERIENCE: Wood treating industry, coke and coal tar distillation industry.

APPLICABLE CHEMICALS OF INTEREST: Suspended solids, oil and grease, polynuclear aromatic hydrocarbons (PAH/Naphthalene), metals.

TECHNOLOGY STATUS: Established technology since the early 1800's.

DESCRIPTION: Filtration is the removal of suspended solids from water by passing it through a porous media. In general, it is a two step process consisting of a filtration and backwashing phase. Water is filtered by passing it through a porous material to remove suspended solids. This can be accomplished with or without the addition of chemicals depending upon the type of solids and/or the desired results. Backwashing takes place whenever solids begin to leak through and/or the head loss through the media becomes significant. Backwash water is generally returned to the beginning of the waste treatment system, which is usually a primary clarifier. Figure 1 illustrates some typical filter configurations.

The efficiency of a filtration unit is depended upon factors such as influent flow rate, filter media type, media pore size and the characteristics of the water to be filtered. Of the several types of filter media available, silica sand is the most common. Crushed anthracite coal and garnet are also frequently used. To decide on the type or types of media to use requires a compromise of the following:

- o smaller grains filter better, produce higher quality effluent, but filter runs are short;
- o larger grains extend the length of filter runs but breakthrough will occur if flow is too high.

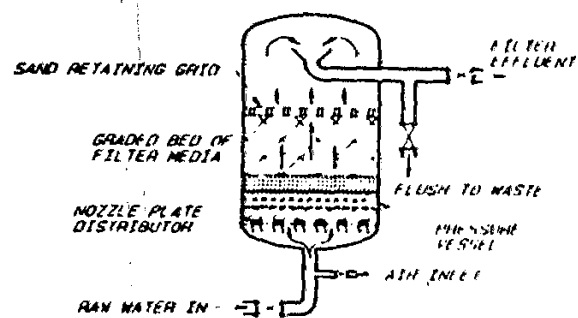
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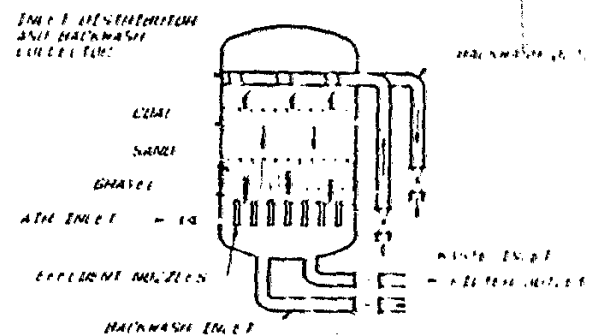
**Ex Situ Treatment
FILTRATION**

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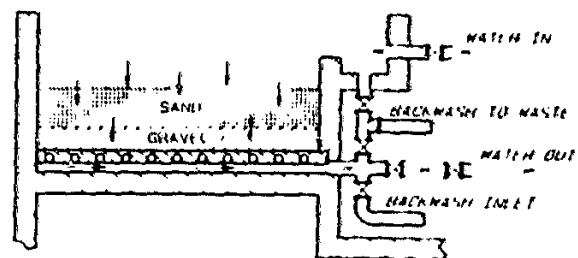
FIGURE 1
TYPICAL FILTER CONFIGURATIONS



TYPICAL UPFLOW
FILTER



TYPICAL PRESSURE
FILTER (DUAL MEDIA)



TYPICAL GRAVITY FILTER

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The ideal filter bed is stratified with coarse to fine media in the direction of flow. This allows for solids penetration into the bed which extends the filter run while maintaining high quality effluent. The development of multimedia and upflow filters was based on this premise. A multimedia bed is stratified according to the specific gravity of its constituents. This makes it possible to have coarser grains at the top of the bed. An upflow filter relies on the natural stratification of a single media with coarser material settling to the bottom.

PERFORMANCE:

Filtration is a proven technology for the removal of suspended solids. Based on available performance data, the following observations can be stated concerning filtration:

- o Suspended solids removal of greater than 80 percent can be achieved,
- o Oil and Grease removal of greater than 50 percent can be achieved,
- o PAH removal decreases as the solubility of the constituent increases,
- o COD removal is a function of its insoluble portion,
- o Removal of phenolics is minimal.

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PHYSICAL/CHEMICAL SEPARATION
(Ex Situ Treatment)

MEDIUM: Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE: Gravity Physical/Chemical Separation

RELATED SITE EXPERIENCE: Petroleum industry, wood treating sites, coking and coal tar distillation sites, manufactured gas plant sites, chemical plants and other industries.

APPLICABLE CHEMICALS OF INTEREST: Oil and grease, suspended solids, polynuclear aromatic hydrocarbons (PAH/Naphthalene).

TECHNOLOGY STATUS: Established technology that has been used in the petroleum industry for several decades. Bench-scale, pilot-scale, full-scale.

DESCRIPTION: Physical/chemical separation can be described as the process of removing the free oils phase from water via natural differences in specific gravity, i.e. oils with a lower specific gravity than water will float while those with a higher specific gravity will sink. The separation process can be enhanced by chemical coagulation/flocculation followed by gravity settling.

Typically, physical/chemical separation is the first operation in a wastewater treatment system. However, it may be necessary to pretreat the waste stream with emulsion breaking chemicals prior to the gravity separator. These emulsion breaking chemicals are generally cationically charged. Usually inorganic chemicals such as ferric chloride, alum and ferrous sulfate or organic low to medium molecular weight polymers are used to destabilize (break) the emulsion. Occasionally, an anionic or nonionic polymer is also required. This second polymer functions as a flocculant which agglomerates the smaller oil particles into larger "flocs", which have improved separation characteristics.

Adjustment of pH may also be used, in conjunction with the other chemicals or alone, to destabilize emulsions or to precipitate other compounds. Jar tests are generally used to select the proper chemicals and dosages for optimum pretreatment and to predict expected effluent quality.

After the wastewater is chemically pretreated, if

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**Ex Situ Treatment
Physical/Chemical Separation**

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required, it flows into the gravity separator where during a quiescent stage the oil phase separates from the water. A typical API separator is illustrated in Figure 1. A removal system for floated and settled material should be part of any separator.

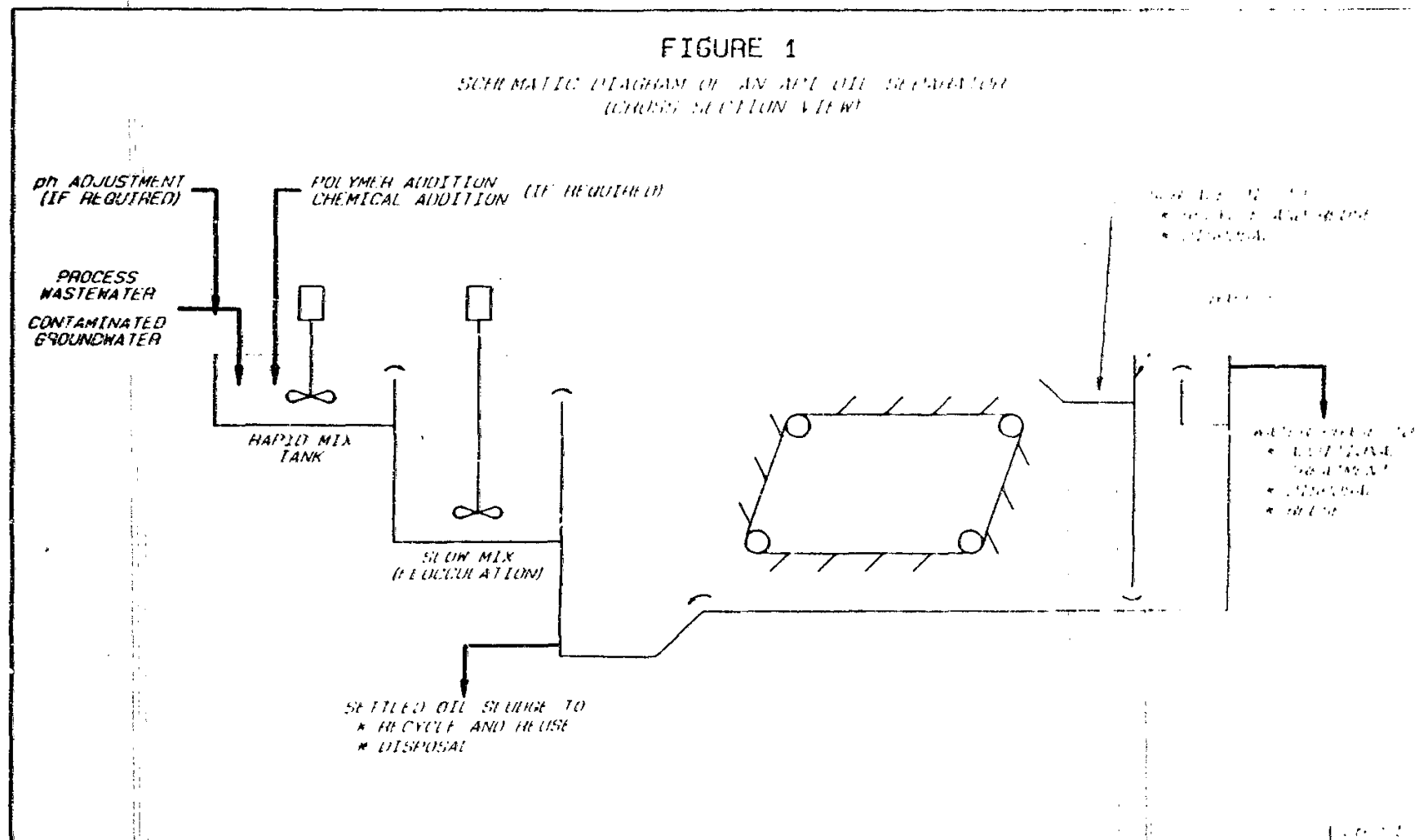
After separation, the water phase can be discharged, reused or receive additional treatment. The oil phase can be recovered, recycled or disposed.

PERFORMANCE:

Physical/chemical separation is proven for the removal of oil and grease and suspended solids. PAH reduction is achieved by removing the portion that stays within the oil phase. Total organic carbon is decreased by the amount contained in the oil and grease and solids that are removed. Existing physical/chemical separation systems have been shown to achieve:

- o Oil and grease and suspended solids reduction near 90% and
- o Total PAH reduction near 80%.

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008281

ION EXCHANGE
(Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE:

Physical Separation

RELATED SITE EXPERIENCE:

Petroleum industry, plating industry.

APPLICABLE CHEMICALS OF INTEREST:

All inorganic cations, such as heavy metals and ammonia, and anions, such as sulfate, identified as chemicals of interest. Also, potentially applicable to ionic organic compounds such as phenolics.

TECHNOLOGY STATUS:

Bench-scale, pilot-scale, full scale. Established technology for treating industrial process wastewaters containing high metals concentrations. Emerging technology for the treatment of ionic organic compounds.

DESCRIPTION:

Ion exchange is a separation process in which selected pollutant ions in an aqueous solution are removed with the use of an ion exchange material, while non-pollutant ions are displaced from the material. In practice, ion exchange "beads" are placed in a column and water to be treated is passed through the bed. Natural ion-exchange materials (zeolites) exist; however, most industrial processing uses synthetic ion exchange resins. These synthetic resins normally are high-molecular-weight organic polymers onto which chemical functional groups (e.g., sulfonic, carboxylic, phenolic, aminos) are added by reaction.

A typical flow diagram for an ion exchange process is presented in Figure 1. A storage tank is normally needed to provide a surge volume in the system, to allow the exchangers to be operated at a constant rate, and to be used to settle coarse solids in the feed water. Untreated water is pumped from the storage tank to the ion exchanger columns. Pretreatment using carbon adsorption or filtration is often required for wastewater.

If a large volume of water is to be treated, two sets of columns should be installed to provide uninterrupted system operation during column regeneration periods. Treated (deionized) water flows by gravity from the columns normally to a treated effluent storage system to allow for monitoring before discharge. Conductivity (a measure of total ion concentration) can be used to

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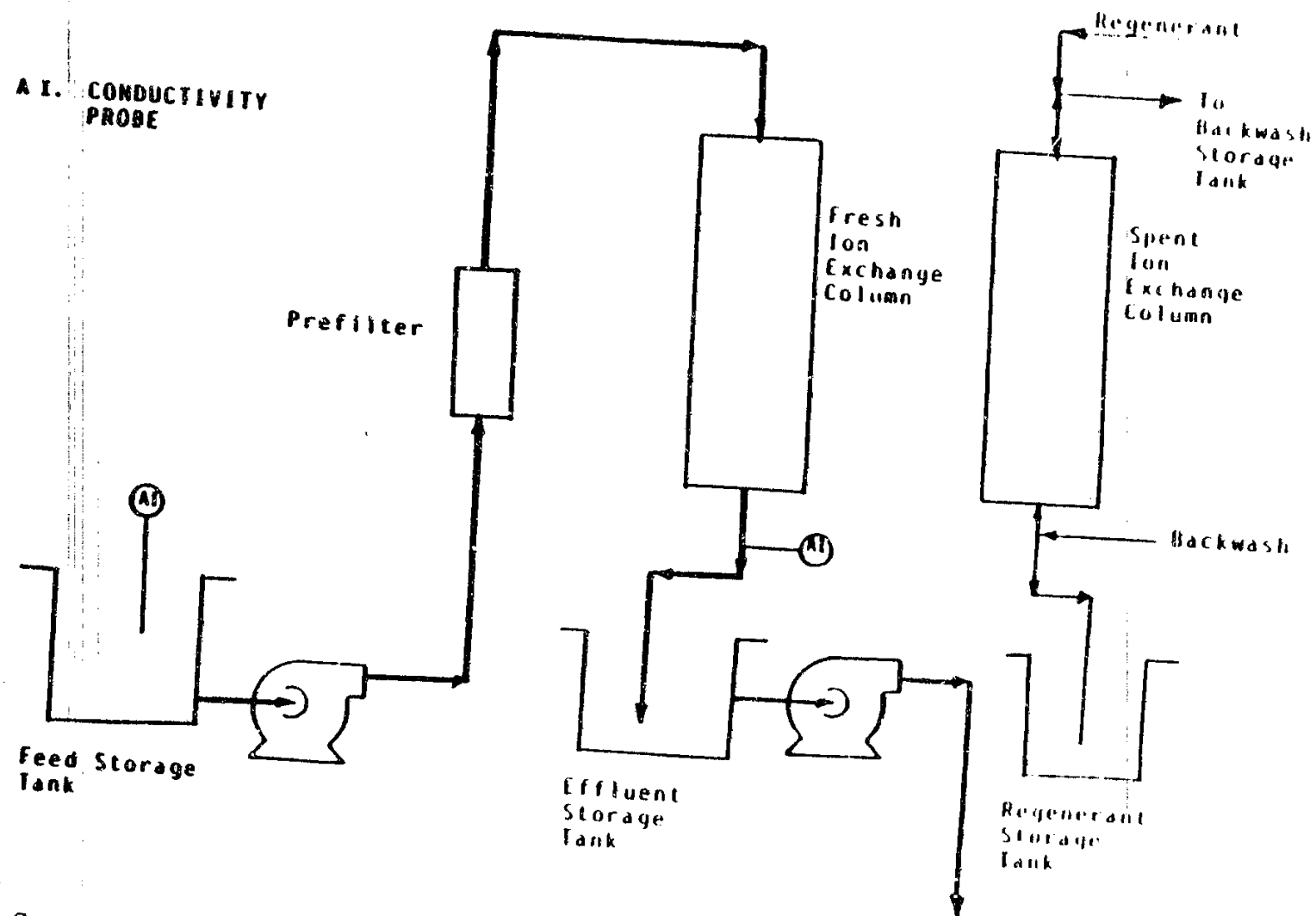
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**Ex Situ Treatment
Ion Exchange**

2
8
2
8
0
0

FIGURE 1

ION EXCHANGE PROCESS SCHEMATIC



Source: Gas Research Institute, October 1987.

0081283 Discharge

determine "breakthrough," at which time the columns are switched and the column with spent resin is regenerated.

With the mixed bed scheme, the regeneration of the ion exchange resin would employ a special operating sequence. The resin bed is first backwashed gently to remove suspended solids and then the resin bed should be fluidized. Diluted hydrochloric acid is pumped from storage through the bed concurrently to the wastewater feed flow. After a water wash, diluted sodium hydroxide is pumped through the bed to convert the anion resin back to the hydroxide form. After another water wash, the column can be returned to service. The various acid, caustic, and wash regenerant solutions which contain concentrated pollutants must be treated or disposed.

PERFORMANCE:

Ion exchange can theoretically remove essentially all of selected ionic constituents if adequate resin contact time and proper resin is used. Industrial experience has shown 50-100 ppb level of various metals are achieved; bench-scale tests have given lower (10 ppb) residuals.

Ion exchange applications for groundwater and surface water treatment have not been identified. Most performance data that have been reported are for plating process wastes which have high metals concentrations. An ion exchange process used to treat a condensate from a refinery achieved removal of hydrogen sulfide to <3 ppm, ammonia to 5 ppm and phenol to 20 ppm.

It must be stressed that the performance of an ion exchange process is very dependent on the composition of the particular wastewater being treated.

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NEUTRALIZATION
(Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE:

Chemical Reaction

**RELATED
SITE EXPERIENCE:**

Petroleum industry, wood treating sites, coke and coal tar distillation sites, manufactured gas plant sites, chemical plants and other industries.

**APPLICABLE
CHEMICALS OF
INTEREST:**

Metals, general inorganics.

**TECHNOLOGY
STATUS:**

Bench-scale, full-scale. Established technology that is generally used in most industries.

DESCRIPTION:

Neutralization is essentially the mixing of an acid and a base. The addition rate of a given neutralizing agent is controlled via pH. The process can be either continuous or batch.

The batch process allows for the greatest control because pH can be monitored and the discharge delayed until the proper pH is attained. Unfortunately, because of storage requirements, the batch process is normally limited to streams with low flows. For medium to high flow streams, some form of a continuous process is required. This requires more elaborate control and feed equipment.

In general, the use of an equalization basin or multiple neutralization units is used when the desired accuracy of the effluent pH is critical. Waste streams where pH stability is low (unbuffered) require multiple neutralizing units. For streams with excessive pH variations, an equalization basin helps to provide a flow with less pH fluctuation.

The choice of a neutralizing agent is generally an economic one. However, compatibility with the waste stream and process equipment must be considered when designing a system.

Mixing of acidic and alkaline waste streams to achieve neutralization, if possible, is usually the most cost effective alternative. However, care should be taken so as not to introduce additional pollutants that require further treatment.

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Consideration should also be given, during design of a system, to the fact that neutralization is an exothermic reaction and, as such, will generate heat. Also, any toxic vapors that may be released should be considered.

The equipment required for neutralization is varied but will generally include: a pH monitor(s), mixer(s), containment and chemical feed equipment. Figure 1 illustrates a typical multiple unit continuous flow neutralization scheme.

PERFORMANCE:

Little relevant performance data is available. Available data indicates that total soluble metals can be decreased by approximately 80%. In general, the degree of treatment that can be achieved depends on the specific application.

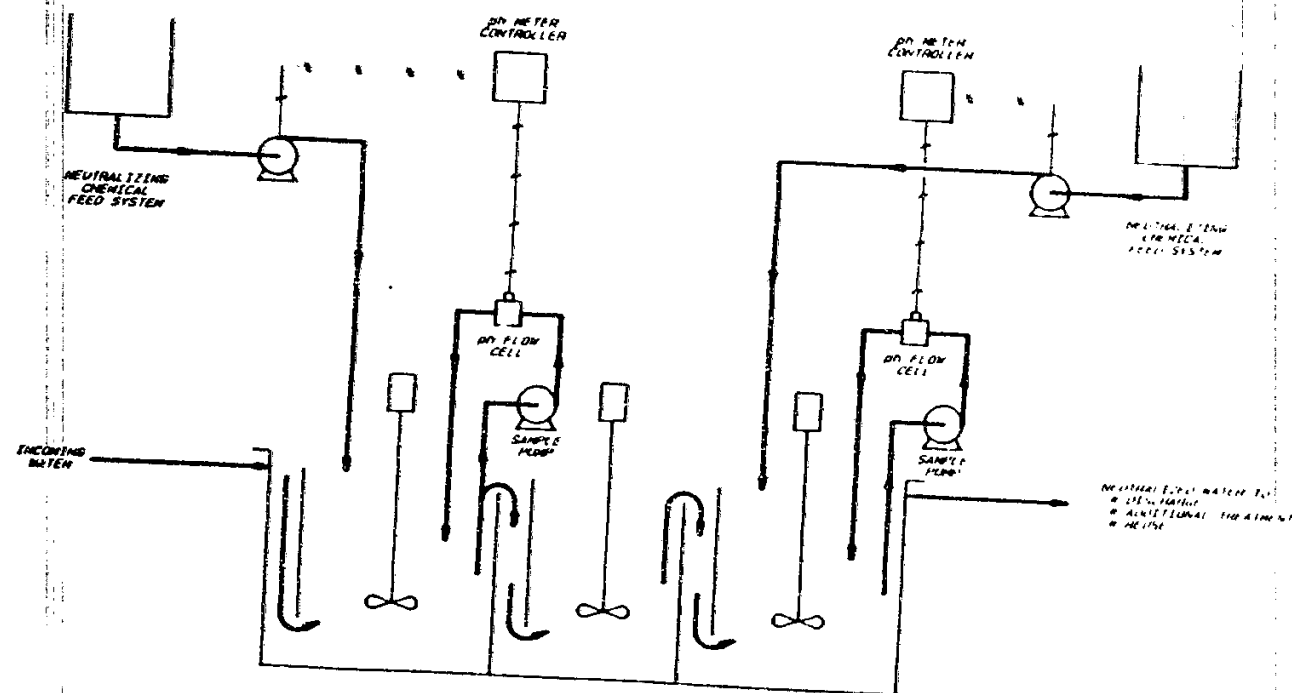
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**Ex Situ Treatment
Neutralization**

FIGURE 1
TYPICAL CONTINUOUS FLOW NEUTRALIZATION PROCESS



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UV CHEMICAL OXIDATION (Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE:

Chemical oxidation in the presence of ultraviolet (UV) light using either hydrogen peroxide (H_2O_2) or ozone (O_3) as the oxidants.

RELATED SITE EXPERIENCE:

Chemical industry, wood treating industry, manufactured gas plant sites, and the coking and coal tar distillation industry.

APPLICABLE CHEMICALS OF INTEREST:

Cyanide, sulfide, volatile organics, phenolics, reduced metals, polynuclear aromatic hydrocarbons (PAH), pesticides, and conventional organic pollutant indicators (BOD_5 , COD, TOC).

TECHNOLOGY STATUS:

Emerging technology with regard to the use of either O_3 or H_2O_2 in the presence of UV light to chemically oxidize organic pollutants.

DESCRIPTION:

Both ozone (O_3) and hydrogen peroxide (H_2O_2) are known oxidizing agents which have the ability to change the form of oxidizable chemical compounds through the process of chemical oxidation. The use of ultraviolet (UV) light in combination with ozone has demonstrated the ability to enhance the reactivity of O_3 or H_2O_2 . Through this process, targeted chemical contaminants are converted to chemical species which are neither harmful nor otherwise objectionable. Given sufficient reaction time and oxidant, many organic compounds will be converted to CO_2 and H_2O .

Hydrogen peroxide is also utilized as an aqueous solution for chemical oxidation. A 35 percent solution is available commercially. This solution is used full-strength or diluted, depending on the specific oxidation application. Metal catalysts are most often used with hydrogen peroxide treatment.

Ozone is cited by some researchers as being the second-most powerful oxidant, exceeded in its oxidation potential only by fluorine. The effectiveness of ozone in oxidizing organic compounds in water is well documented. Ozone has been used in Europe since 1903 for the treatment of drinking water. Ozone is an unstable compound and must be generated on-site. For

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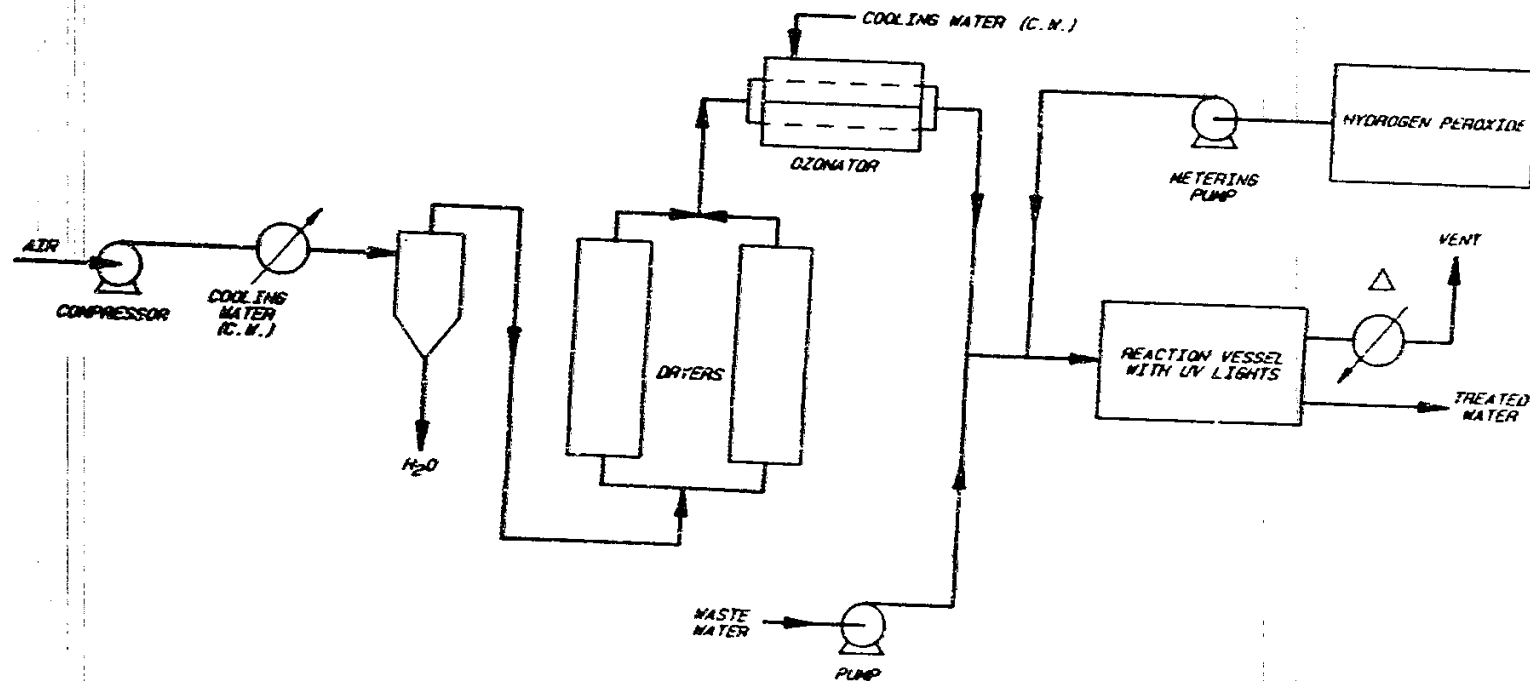
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Ex Situ Treatment
UV Chemical Oxidation

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FIGURE 1

UV CHEMICAL OXIDATION TREATMENT SYSTEM SCHEMATIC



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commercial applications, ozone is produced through the discharge of an electric current across an air stream containing oxygen. The ozone enriched gas stream is contacted with the water targeted for treatment in a reaction vessel.

The UV light effect related to the basic law of photochemistry in that light that is absorbed by a chemical compound will cause an absorbed chemical or physical change in the chemical. The absorbance of UV light typically causes a transition of electrons and a subsequent breaking apart of the chemical compound. Once this occurs, the chemical may be more susceptible to chemical oxidation by either O_3 or H_2O_2 . While this description offers a very simplified view of the UV Chemical Oxidation process, much research work is presently being carried out to better understand and quantify the complex chemistry associated with this treatment process.

A schematic of a UV Chemical Oxidation system is given in Figure 1. For the UV Chemical Oxidation process the reaction vessel design is altered to accommodate ultraviolet lights.

Ozone can be generated from oxygen or air. Compressed air is used as the feed source in most applications. The air must be dried and filtered before being sent to the ozone generator. Ozone generating equipment operating on an air feed source produces an ozone concentration in the exit gas of 1 - 2 weight percent. With an oxygen feed source, a higher weight percent of ozone (3-4%) is produced in the discharge from the generator. Oxygen is normally utilized only in very large systems due to economic reasons. Hydrogen peroxide is added in liquid form directly to the reaction vessel via a metering pump.

The reaction vessel is designed to provide intimate contact between the oxidant and the water to be treated. Several reactor configurations are available. Reactors are typically a minimum of 15 feet tall to ensure that adequate contact time is available for the ozone to be reacted. The oxidant is introduced into the bottom of the reactor. The units are normally designed to be operated in a countercurrent flow regime to enhance mass transfer. Off gas from an ozone reactor may require treatment for destruction of residual ozone prior to discharge to the atmosphere.

For this process the reactor design is modified to include the ultraviolet lamps. A typical UV reactor has several chambers separated by baffles designed to provide a tortuous flow regime. Each chamber is equipped with a

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number of low pressure ultraviolet lamps.

PERFORMANCE:

Ozone and hydrogen peroxide are powerful oxidizing agents which have the ability to degrade organic compounds through chemical oxidation. The use of ultraviolet light in combination with either O_3 and H_2O_2 has been shown to enhance their reactivity with certain chemical constituents. The degree to which UV Chemical Oxidation oxidizes organic compounds is dependent upon: (i) the oxidant dosage, (ii) the initial concentration of chemicals in solution and (iii) their molecular structure. Review of the literature data suggests that there is competition among different chemical groups for the available oxidant and absorbance of UV light.

UV Chemical Oxidation with either O_3 or H_2O_2 has been shown to achieve the following:

- o Between 20 to 90 percent removal of cyanide,
- o Between 25 to 99 percent removal of sulfide,
- o Between 10 to 99+ percent removal of phenolics and
- o Between 50 and 99+ percent removal of polynuclear aromatic hydrocarbons.

The process appears to be well suited for reduction of phenolics, polynuclear aromatic hydrocarbons, naphthalene, and cyanide. For the case of cyanide, ozone in the presence of UV light also has the potential to break the iron-cyanide complex, which cannot be accomplished biologically. Additional work is required to establish the capability of this technology to treat chemical compounds at site specific concentrations.

008291

PHOTOLYSIS (Ex Situ Treatment)

MEDIUM:

Groundwaters and aqueous or solvent extracts of soil or sludges.

PROCESS TYPE:

Photochemical

RELATED SITE EXPERIENCE:

None

APPLICABLE CHEMICALS OF INTEREST:

PCB's, PCP, dioxins and other toxic chlorinated compounds are susceptible to photolysis -- initiated dechlorination. Chemicals of interest are candidates of UV catalyzed oxidation (using ozone, chlorine, or peroxide) as discussed in a separate technology description.

TECHNOLOGY STATUS:

Emerging technology. Bench-scale, pilot-scale, full-scale.

DESCRIPTION:

Two general types of photo reactions can be used in photochemical treatment of wastes; direct photolysis and indirect photolysis. Direct photolysis involves light adsorption by the substrate followed by chemical reaction of the substrate in its electronically excited state. Direct photolysis is the only pathway for photoreaction in a reaction medium that is transparent to incident light.

Indirect photoreactions involve chemical reaction of a substrate that is induced through light adsorbance by another substrate in the system. Indirect photoreactions are mediated by excited states of photosensitizers, by free radicals of various types and by other short-lived reaction transients.

PERFORMANCE:

U.V. photolysis can be used to "catalyze" or initiate the dechlorination of organic chemicals in either aqueous or solvent systems. Degradation products of these reactions include polymeric tars and oxygenated compounds (in aqueous systems). Treatment (>95% conversion) of chlorophenols to below 1 ppm and chlorinated dioxins to 1 ppb in a solvent system has been demonstrated. No treatability data for chemicals of interest have been found.

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Ex Situ Treatment
Photolysis

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REVERSE OSMOSIS
(Ex Situ Treatment)

MEDIUM: Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE: Physical

RELATED SITE EXPERIENCE: None

APPLICABLE CHEMICALS OF INTEREST: Metals, ammonia, nitrate, cyanide, thiocyanate, sulfate, dissolved solids, organics with a molecular weight greater than 200.

DESCRIPTION: Reverse osmosis is normally the final unit operation in a water treatment system, as it produces a very high quality effluent. Pretreatment is required ahead of reverse osmosis to remove materials which may foul or chemically degrade the membrane. Pretreatment processes which are typically employed include pH adjustment, softening, filtration and chlorination/dechlorination.

The effluent from a reverse osmosis unit will include a permeate (clean water) stream and a concentrate (reject) stream. A schematic of a typical reverse osmosis system is given in Figure 1. The permeate stream is normally suitable for discharge, unless low molecular weight organics are a concern. The concentrate stream may require additional treatment, such as evaporation, if it cannot be reused in a process or directly disposed of.

Major components in a reverse osmosis unit include a feed pump, a prefiltration system, one or more high pressure pumps, a series of pressure vessels containing the membranes and associated monitoring and control equipment. A cooling water supply is required to dissipate the heat added to the system by the high pressure pumps.

Membranes for the unit are available in several basic configurations, the most common being hollow fiber, spiral wound and tubular. Until recently, cellulose acetate was the primary material of construction for the active layer of reverse osmosis membranes. Membranes utilizing active layers of polyamide and polysulfone construction are now available and offer potential advantages over cellulose acetate in the areas of pH sensitivity, chemical resistance and water flux rates. The membrane of choice for a particular application is

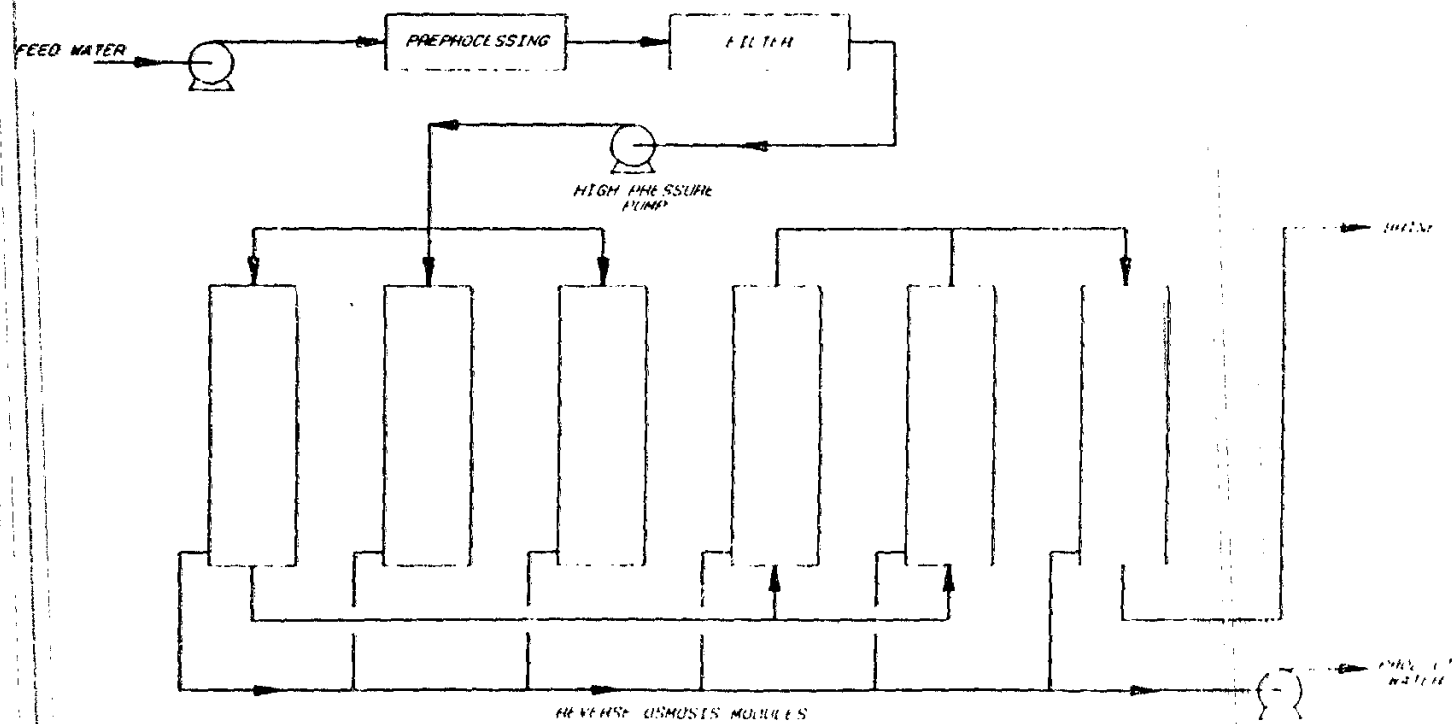
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Ex Situ Treatment
Reverse Osmosis

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FIGURE 1
REVERSE OSMOSIS PLANT FLOWSHEET



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generally determined through pilot scale testing.

PERFORMANCE:

Reverse osmosis system performance is affected by a number of operating variables and information regarding effluent water quality is generally determined on a case by case basis through bench or pilot scale testing. Table 1 and Table 2 present typical membrane performance data for a variety of inorganic and organic compounds, respectively, as provided by a membrane manufacturer.

Reverse osmosis produces a high quality effluent stream which is normally suitable for direct discharge. The major exception to this would be the presence of low molecular weight organic compounds, such as phenolics, in the water to be treated. Treatability work with phenolic contaminated wastewaters has indicated that removals of less than 50% are achieved for these compounds.

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TABLE 1

TYPICAL MEMBRANE REJECTIONS/PASSAGES - INORGANICS

Name	Symbol	Percent Rejection	Percent Passage (Average)	Maximum Concentration Percent
Cations				
Sodium	Na ⁺	94-96	5	5-10
Calcium	Ca ⁺²	96-98	3	*
Magnesium	Mg ⁺²	96-98	3	*
Potassium	K ⁺¹	94-96	5	5-10
Iron	Fe ⁺²	98-99	2	*
Manganese	Mn ⁺²	98-99	2	*
Aluminum	Al ⁺³	99+	1	10-20
Ammonium	NH ₄ ⁺¹	88-95	8	3-8
Copper	Cu ⁺²	98-99	1	10-20
Nickel	Ni ⁺²	98-99	1	10-20
Zinc	Zn ⁺²	98-99	1	10-20
Strontium	Sr ⁺²	96-99	3	-
Hardness	Ca and Mg	96-98	3	*
Cadmium	Cd ⁺²	96-98	3	10-20
Silver	Ag ⁺¹	94-96	5	*
Mercury	Hg ⁺²	96-98	3	-
Anions				
Chloride	Cl ⁻¹	94-95	5	5-8
Bicarbonate	HCO ₃ ⁻¹	95-96	4	5-10
Sulfate	SO ₄ ⁻²	99+	1	5-15
Nitrate	NO ₃ ^{-1**}	85-95	10	3-6
Fluoride	F ⁻¹	94-96	5	5-8
Silicate	SiO ₂ ^{-2**}	80-95	10	-
Phosphate	PO ₄ ⁻³	99+	1	10-20
Bromide	Br ⁻¹	94-96	5	5-8
Borate	B ₄ O ₇ ^{-2**}	35-70**	-	-
Chromate	CrO ₄ ^{-2**}	90-98	6	8-12

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TABLE 1(Continued)

TYPICAL MEMBRANE REJECTIONS/PASSAGES - INORGANICS

Name	Symbol	Percent Rejection	Percent Passage (Average)	Maximum Concentration Percent
Cyanide	CN^{-1**}	90-95**	-	4-12
Sulfite	SO_3^{-2}	98-99	1	5-15
Thiosulfate	$\text{S}_2\text{O}_3^{-2}$	99+	1	10-20
Ferrocyanide	$\text{Fe}(\text{CN})_6^{=3}$	99+	1	10-20

* Must watch for precipitation, other ion controls maximum concentration.

** Extremely dependent of pH; tends to be an exception to the rule.

008297

TABLE 2
TYPICAL MEMBRANE REJECTIONS/PASSAGES - ORGANICS

	Molecular Weight	Percent Rejection	Maximum Concentration Percent
Sucrose sugar	342	99.9	30-35
Lactose sugar	360	99.9	30-35
Protein	10,000 up	99.9+	50-80
Glucose	180	99	15-20
Phenol	94	***	--
Acetic acid	60	***	--
Formaldehyde	30	***	--
Dyes	400 to 900	99.9	--
Biochemical Oxygen Demand (BOD)		90-99.9	--
Chemical Oxygen Demand (COD)		99.9	--
Urea	60	40-60	Reacts similar to a salt
Bacteria & virus	500,00-50,000	99.9+	--
Pyrogen	1000-5000	99.9+	--

*** Permeate is enriched in material due to preferential passage through the membrane.

008298

SOLVENT EXTRACTION
(Ex Situ Treatment)

MEDIUM:

Heavily contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE:

Preferential absorption of chemicals of interest into water insoluble solvent liquid.

RELATED SITE EXPERIENCE:

Used by the chemical industry, the pharmaceutical industry, and the coking and coal tar distillation industry for treatment of process wastewaters where chemical recovery is economically warranted.

APPLICABLE CHEMICALS OF INTEREST:

Volatile organics, phenolics, polynuclear aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB).

TECHNOLOGY STATUS:

Established technology with regard to chemical processing and process wastewater treatment where chemical recovery is economically warranted. Bench-scale, pilot-scale and full-scale.

DESCRIPTION:

With regard to removal of organic chemical compounds from an aqueous stream, solvent extraction refers to a process whereby the liquid water is contacted with a liquid solvent which results in targeted chemical compounds being preferentially absorbed into the solvent phase thereby being removed from the water stream. The solvent is usually immiscible with water, having a density either greater or less than water depending upon the particular solvent being used. The choice of solvent is determined by the targeted chemicals to be removed. Once in the solvent phase, the solvent can be disposed of or regenerated by selective removal of the contaminant chemical compounds from the solvent.

Extraction equipment may be operated batchwise or continuously. For either mode, the water and the solvent must be brought into good contact to permit transfer of chemical compounds from the aqueous phase to the solvent phase. For the batch operation mode, a quantity of aqueous liquid is mixed with a quantity of solvent in an agitated vessel, after which the immiscible layers are allowed to settle and are separated into the extract and raffinate phases. The raffinate refers to the treated water reduced in chemical contaminants, and the

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**Ex Situ Treatment
Solvent Extraction**

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extract refers to the solvent containing the absorbed chemical contaminants.

With regard to continuous treatment operation, Figure 1 depicts a mixer-settler extraction system. For continuous flow, the mixer and settler must be separate pieces of equipment. The mixer may be a small agitated tank provided with inlets and a drawoff line and baffles to prevent short-circuiting; or it may be a centrifugal pump or other flow mixer. The settler is often a simple continuous gravity decanter. As illustrated, several contact stages are usually required with a train of in series mixers-settlers operated. The raffinate, i.e. the treated water, from each settler becomes the feed to the next mixer, where it meets intermediate extract, i.e. solvent with absorbed chemicals, or fresh solvent. The process results in a continuous countercurrent flow of water to be treated and solvent.

Figure 2 depicts a continuous tower extractor process. Here, as heavier liquid added to the top of the extractor flows downward, it contacts the lighter liquid rising upward. This results in a continuous transfer of material between the two different phases with the composition of each phase changing as it flows through the tower reactor. The reaction zone may be a series of trays, packed media, or an agitated zone. Depending upon specific conditions. The heavy or light liquid could refer to either the water to be treated or the solvent.

PERFORMANCE:

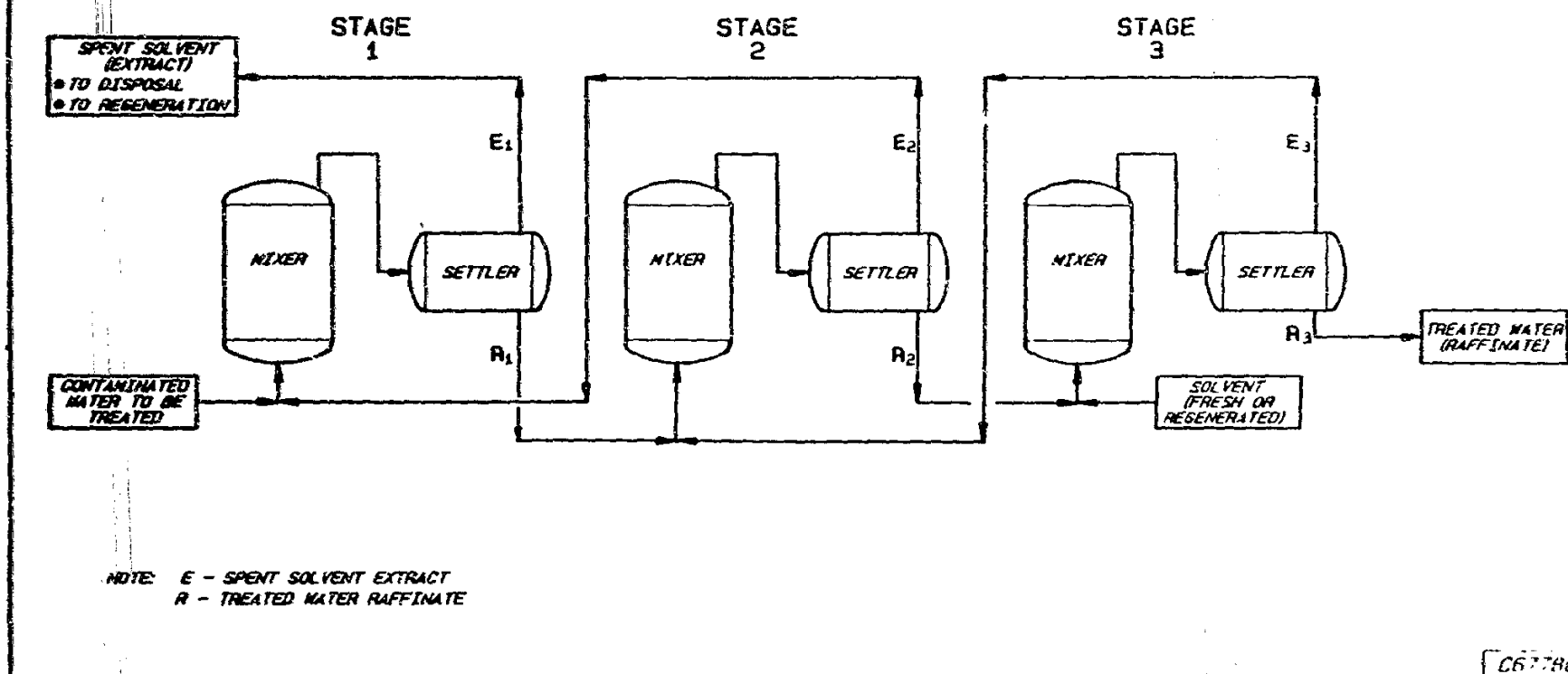
As previously stated, solvent extraction is best suited for gross reduction of chemical contaminants from water where product recovery is economically warranted. As such, it is not a viable technology where low concentration of chemicals in solution is required.

The main applications to which solvent extraction is best suited is treatment of process wastewaters with subsequent product recovery. Examples include phenol recovery, acetic acid recovery and recovery of pharmaceuticals and other organics from process wastewaters.

Screening of different solvents can easily be achieved through bench-scale testing.

FIGURE 1

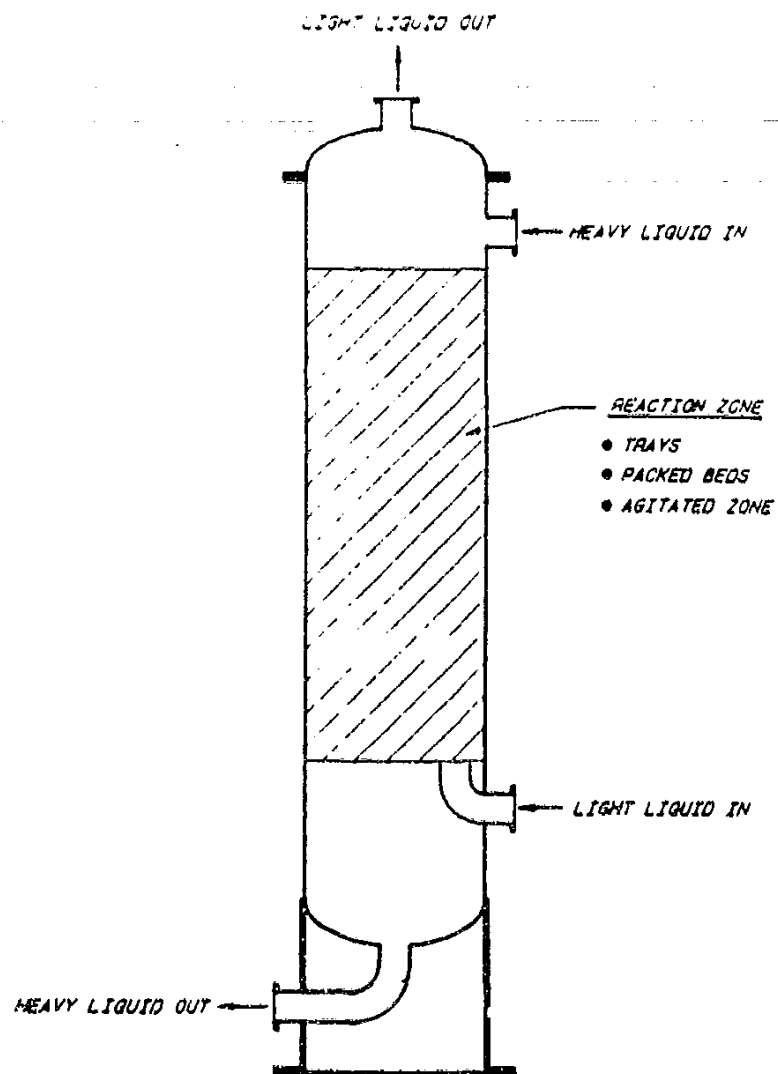
SCHEMATIC DIAGRAM OF A CONTINUOUS MIXER-SETTLER
SOLVENT EXTRACTION PROCESS



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FIGURE 2

PROCESS SCHEMATIC FOR CONTINUOUS
COLUMN REACTOR SOLVENT EXTRACTION



NOTE: HEAVY OR LIGHT LIQUID COULD REFER TO EITHER THE CONTAMINATED WATER TO BE TREATED OR THE SOLVENT. THE CHOICE DEPENDS UPON THE PARTICULAR CHEMICAL CONTAMINANTS TO BE REDUCED IN THE WATER PHASE.

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008302

WET AIR OXIDATION
(Ex Situ Treatment)

MEDIUM:

Aqueous or aqueous-organic (including sludges).

PROCESS TYPE:

Chemical Destruction

RELATED SITE EXPERIENCE:

None.

APPLICABLE CHEMICALS OF INTEREST:

All organic chemicals of interest, cyanide, sulfide.

TECHNOLOGY STATUS:

Established technology as a sludge conditioning technique at municipal wastewater (biological) treatment plants. Emerging technology for industrial wastewater treatment.

DESCRIPTION:

Wet Air Oxidation (WAO) is the oxidative degradation of organics in aqueous streams using air as the oxygen source. Destruction of most organics requires temperatures between 350 and 650°F and pressures of 1,000 to 3,000 psig. WAO may be appropriate for aqueous waste streams that are too dilute for economical incineration. Most organics can be treated by WAO, although the reaction conditions required vary considerably between different types of compounds. In WAO the destruction efficiency for the original organic is typically greater than 99 percent. COD reduction ranges from 75 to 95 percent. Final degradation products of the initial organics include carboxylic acids as well as carbon dioxide and water. Catalysts have been shown to increase the oxidation reaction rates and increase the conversion (degree of oxidation). Since complete oxidation of all organics (100 percent COD reduction) is not normally economically feasible, effluent from a WAO process must usually undergo further treatment. This would typically be bio-treatment in an on-site system or by discharge to a POTW, since wet oxidation generally converts organics to partially oxidized molecules which are more amenable to biological treatment. Catalysts have been investigated to improve WAO technology performance and applicability.

In typical WAO systems wastewater and air are continuously injected into a high pressure reactor. Heat is supplied by the heat-of-reaction of the oxidation process, although auxiliary heat input may be required for start-up or for aqueous wastes having very low organic concentrations. WAO reactor effluent is cooled

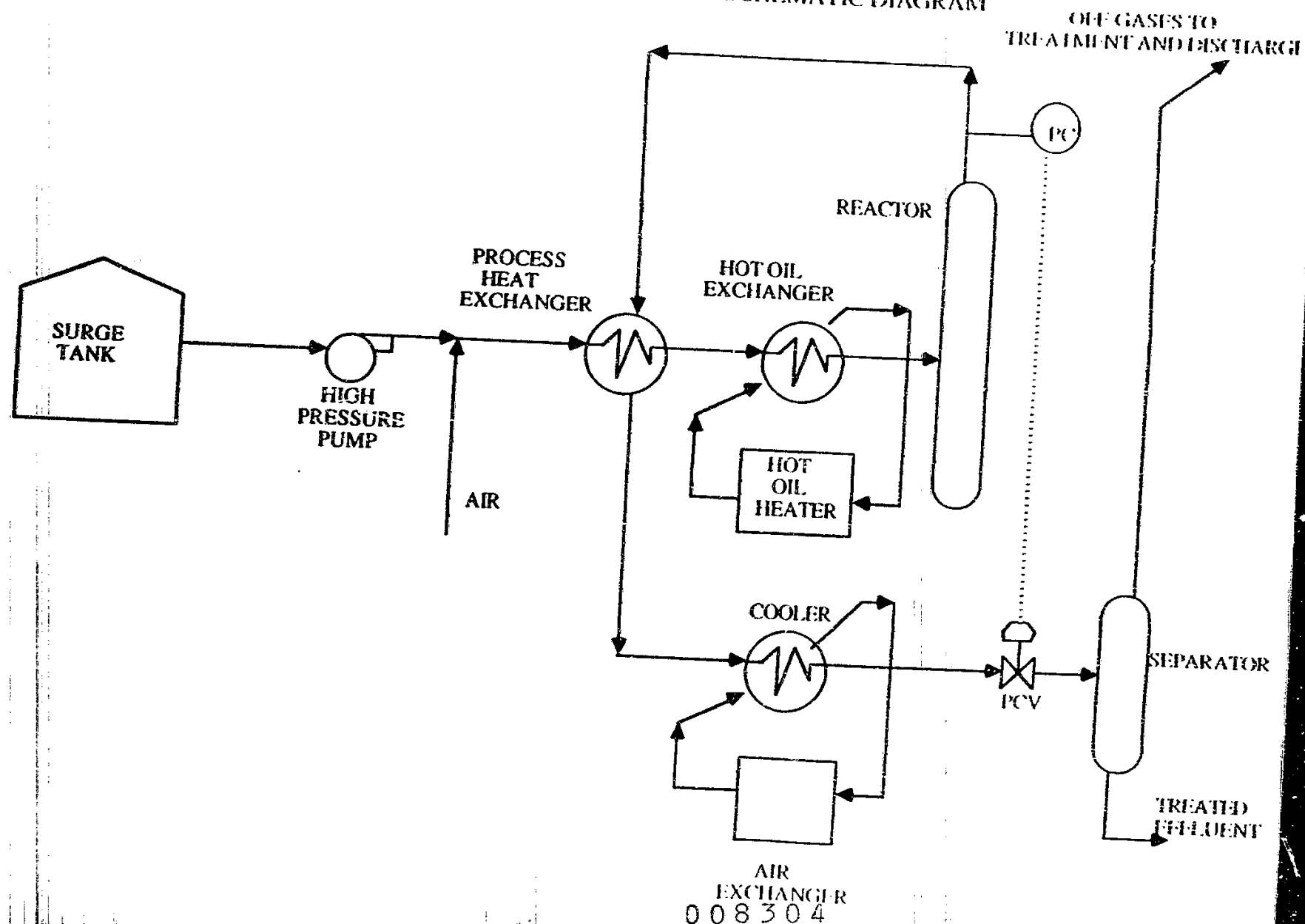
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**Ex Situ Treatment
Wet Air Oxidation**

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FIGURE 1
WET AIR OXIDATION PROCESS SCHEMATIC DIAGRAM



prior to discharge. Non-condensable "combustion" gases (nitrogen and carbon dioxide) which are generally free of acid gases, but may contain some volatile hydrocarbons, are vented to the atmosphere, after emission control as necessary.

A typical flow diagram of the wet air oxidation unit is shown in Figure 1. Influent seed can be pumped to holding tanks in order to achieve a fairly constant flow and composition. The feed is pumped to the system using a positive displacement high pressure pump. These pumps can accommodate low levels (less than 5 percent) of fine non-abrasive solids. The feed is heated in a feed/effluent exchanger. Air is introduced at the high pressure pump or injected directly into the bottom of the wet oxidation reactor.

The heat released by the oxidation reactions raises the reactor temperature to between 400 and 600°F. Preheating of the feed may be necessary to maintain the reactor operating temperature for waste streams that do not contain enough oxidizable organic to supply adequate heat. Alternatively, fuel might be added directly to the waste to increase its heating value.

Hot oxidized effluent is cooled by heat exchange with the reactor feed before pressure let down through a control valve. Liquid and non-condensable gases are disengaged in a separator drum. The treated wastewater from the separator typically contains carboxylic acids, aldehydes and other simple oxygenated hydrocarbons. The non-condensable gases contain oxygen, nitrogen, carbon dioxide and some volatile hydrocarbons. These gases may undergo further treatment before discharge to the atmosphere. This might include vapor phase carbon adsorption, fume incineration, or scrubbing.

PERFORMANCE:

Full-scale experience indicates that the toxicity of wastewaters with high levels of organics can be greatly reduced by WAO treatment. Typical WAO treatment can destroy 99 percent or more of phenols, cyanides, aromatics and PAH in wastewater. Effluent concentrations of 1 ppm or lower have been achieved in laboratory or pilot studies. WAO treated wastewater usually requires further treatment (e.g., biological) to remove intermediate oxidation products.

SONIC TREATMENT (Ex Situ Treatment)

MEDIUM:

Contaminated pumped groundwaters, segregated surface waters and process wastewaters.

PROCESS TYPE:

Physical separation

RELATED SITE EXPERIENCE:

Petroleum industry.

APPLICABLE CHEMICALS OF CONCERN:

The insoluble portion of all the organic chemicals of interest.

TECHNOLOGY STATUS:

Bench-scale, pilot-scale, full-scale. An emerging technology with full-scale applications in the petroleum industry.

DESCRIPTION:

Sonic energy can be used to break emulsions of hydrocarbon and water which may also contain suspended solids. This is strictly a mechanical process; no chemicals are required. Sonic treatment works by delivering mechanical energy (sound or compression waves) to the surface of the dispersed droplets in the emulsion. This ruptures the surface of the droplets and results in their coalescing into larger drops. These drops can then be removed by settling or centrifugation. Since hydrocarbons are poor transmitters of sound waves, sonic treatment requires water as the continuous phase. Emulsions of hydrocarbon droplets dispersed in water can be treated as is. Emulsions with hydrocarbons as the continuous phase require the addition of extra water. This water can be recycled back from the final phase separation so that no extra wastewater is generated.

A schematic diagram representing a typical sonic energy emulsion breaking system is shown in Figure 1. Emulsions or sludges can be pumped from contaminated wells or ponds to a heated storage/equalization tank. Equalization is needed to provide a uniform flow and composition to the sonic treatment unit. Emulsion from the tank is pumped to the treatment unit where it is subjected to sonic vibration at approximately 18 to 27 kilohertz. Typical sonic treatment units have a rectangular chamber with a residence time of 5 to 10 minutes.

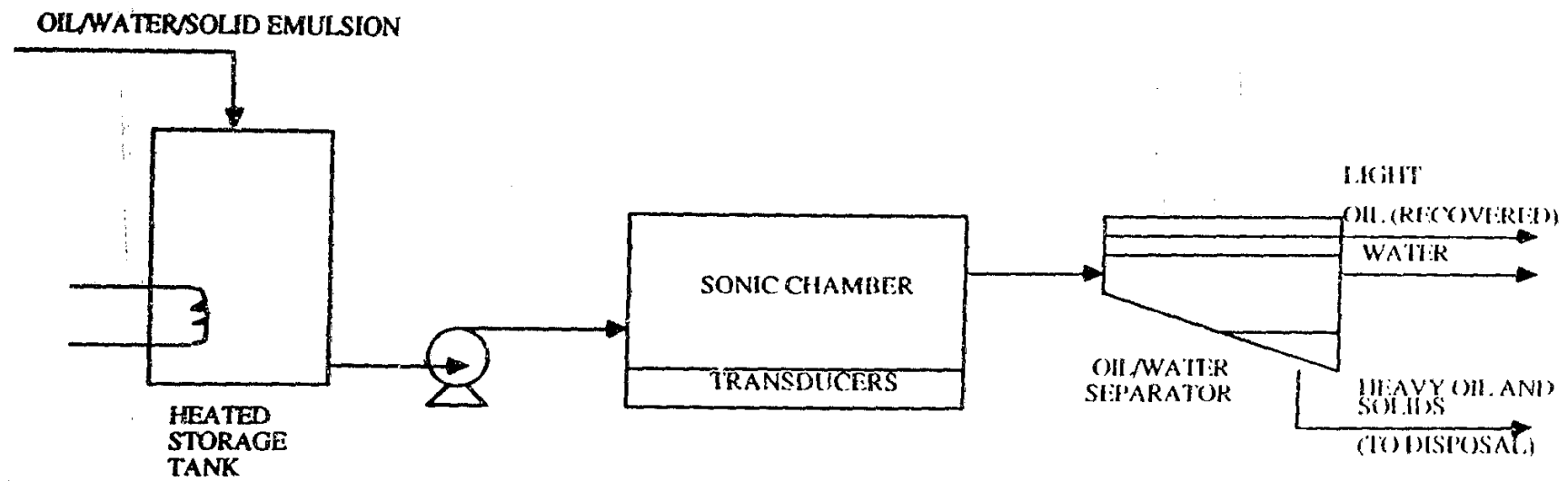
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Ex Situ Treatment
Sonic Treatment

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FIGURE 1
SONIC TREATMENT PROCESS SCHEMATIC DIAGRAM



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PERFORMANCE:

Sonic treatment has been demonstrated on a large scale at a refining company facility in Colorado. In this project, a low solids, 50/50 mixture of water and heavy hydrocarbon sludge was processed in a sonic treatment unit at 12 gpm. Eventually 60,000 barrels of oil fraction was recovered and sold as No. 6 fuel oil. No data on concentrations of dissolved or entrained organics in the aqueous phase were reported.

A company experienced with sonic treatment reportedly has a pilot unit which has been used to treat API separator sludges, tank bottom sludges and other refinery emulsions.

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3.3 ON-SITE SOIL/RESIDUE TREATMENT

COMPOSTING

ENGINEERED BIODEGRADATION SYSTEMSM(EBDSSM)

INCINERATION

SOIL WASHING

STABILIZATION

THERMAL DESORPTION

008309

COMPOSTING
(Ex Situ Treatment)

MEDIUM:

Contaminated soils, sludges and tars.

PROCESS TYPE:

Biological

RELATED SITE EXPERIENCE:

Manufactured gas plants, chemical plants.

APPLICABLE CHEMICALS OF INTEREST:

Soluble organics.

TECHNOLOGY STATUS:

Established technology for the conditioning of municipal treatment sludges. Emerging technology for industrial applications. Bench-scale, pilot-scale, full-scale.

DESCRIPTION:

Composting is a biological process used typically for the treatment of wastes with high concentrations of biodegradable organic solids. This process is generally applied to the treatment of contaminated solids/soils, although concentrated waste streams have been treated following blending with a bulking agent. Waste destruction and conversion is achieved by the use of thermophilic aerobic microorganisms which occur naturally in decaying organic matter. The use of specialized microbial strains, not typically considered composting, has become an increasingly popular method of treatment for compounds thought previously to be resistant to biodegradation.

The composting process is a four step procedure operated continuously to achieve a high degree of waste reduction. The first step involves the mixing of wastes with a bulking agent to enhance aerobic conditions. This is done by increasing porosity, thus providing greater oxygen transfer, and also by decreasing the moisture content of the mass. Secondly air, and indirectly heat, are introduced to the system promoting the thermophilic conditions necessary for aerobic decomposition of the soluble organic wastes. Next further waste stabilization is achieved by a curing step. The last step involves the separation of the bulking agent from the stabilized sludge for reuse. A schematic of this four step process is shown in Figure 1.

PERFORMANCE:

The specific application of this technology to chemicals

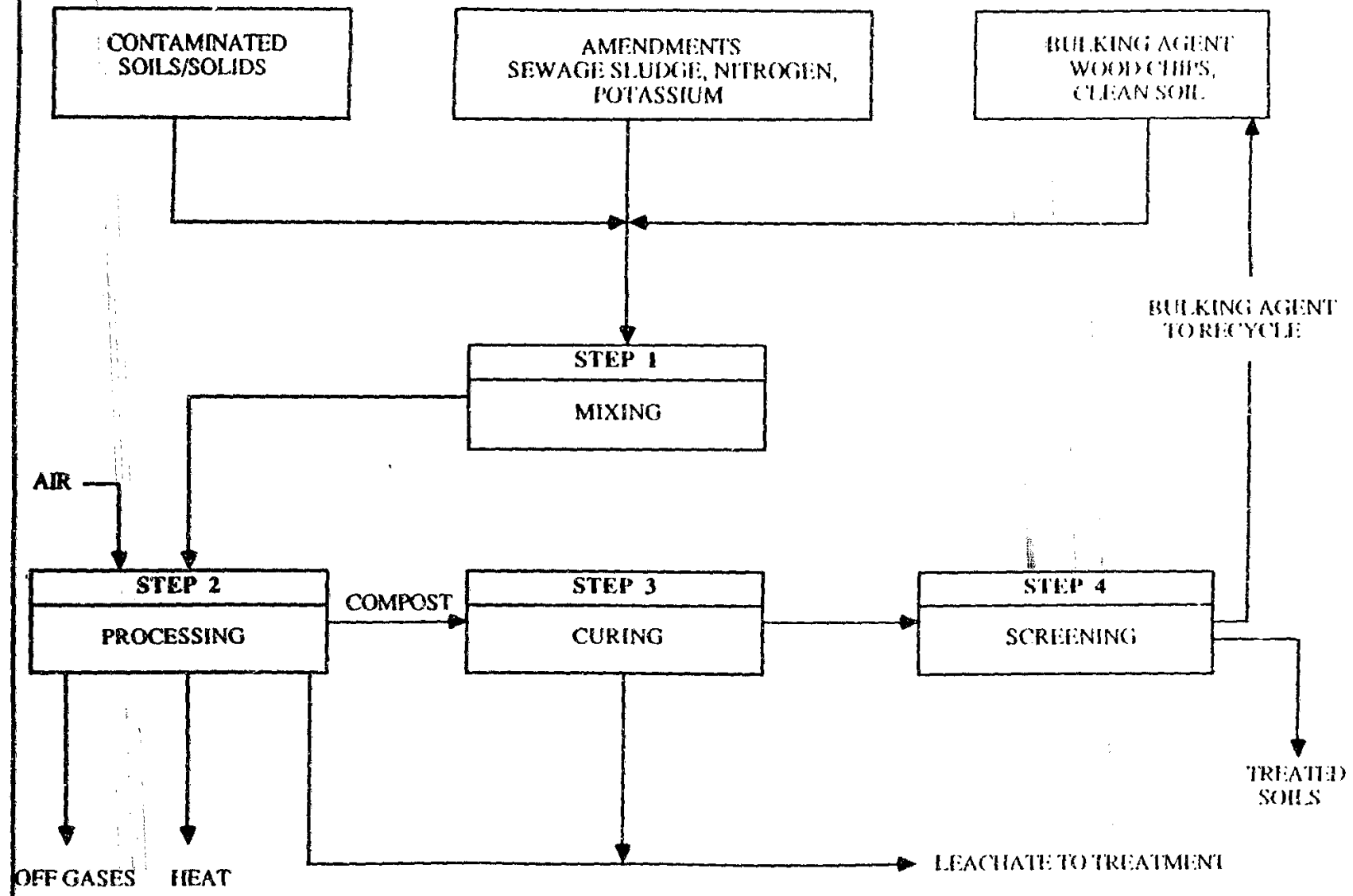
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**Ex Situ Treatment
Composting**

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FIGURE 1
COMPOSTING PROCESS SCHEMATIC



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of interest is uncertain. Some preliminary studies show promising results, although final contaminant-specific end points have not been determined. A summary of relevant results is as follows:

- o Greater than 62% degradation of pyrene and chrysene degradation in excess of 25% in a short term laboratory study.
- o Greater than 90% degradation of coal tars achieved during an MGP facility remedial effort.

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ENGINEERED BIODEGRADATION SYSTEMSM (Ex Situ Treatment)

MEDIUM:

Excavated surface and subsurface soils.

PROCESS TYPE:

Biological (aerobic or anaerobic) oxidation, adsorption/desorption, volatilization.

RELATED SITE EXPERIENCE:

Petroleum industry, wood treating industry, coke and coal tar distillation industry, manufactured gas plant sites and other organic chemical industries.

APPLICABLE CHEMICALS OF INTEREST:

Biodegradable inorganics (e.g. sulfide, cyanide, ammonia), phenolics, polynuclear aromatic hydrocarbons (PAH), volatile organics, polychlorinated biphenyls (PCB), and conventional pollutant parameters indicative of organic compounds (e.g. BOD₅, COD, TOC).

TECHNOLOGY STATUS:

Conventional land treatment is an established technology for the petroleum industry. Engineered BioDegradation SystemSM (EBDSSM) treatment represents Keystone's engineered approach of a land treatment technology for contaminated soils. In this regard, EBDSSM is an emerging technology gaining acceptance for economical treatment of excavated surface and subsurface contaminated soils. Bench-scale, pilot-scale and full-scale applications have been carried out.

DESCRIPTION:

Keystone's Engineered BioDegradation SystemSM (EBDSSM) soil treatment technology is a proprietary process for biological treatment of contaminated soils. A service mark and patent under the name Engineered BioDegradation SystemSM, or EBDSSM, have been applied for. EBDSSM soil treatment is defined as a unit process that treats contaminated soil utilizing the capacity of the soil matrix to biodegrade and immobilize the contaminants of interest. For such treatment, the proper environment must be maintained to promote and sustain biological activity.

EBDSSM soil treatment process design is based on a number of factors including:

- o Contaminant types, concentration levels and extent,
- o Physical and chemical properties of the contaminants,

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- o Soil type and characteristics,
- o Hydrogeological conditions,
- o Site topography,
- o Meteorologic conditions,
- o Proximity of site to receptors,
- o Potential emissions,
- o Potential exposure pathways,
- o Acceptable exposure levels (AEL) and
- o Future development plans.

Figure 1 schematically illustrates that EBDSSM soil treatment is an aerobic soil mixture approximately 0.5 to 1.5 feet deep that is managed to promote the growth of indigenous microorganisms to biodegrade contaminants and to promote immobilization of contaminants. The figure also indicates the numerous factors accounted for in design and operation of an EBDSSM soil treatment process. The contaminated soil can be handled in a variety of manners to minimize odors and provide good distribution by plowing, disc harrowing, or other similar methods. Blending of highly contaminated soils with soils of lesser amounts of contamination is sometimes necessary depending upon the type and concentration of contamination. The mixing also provides aeration of the soils to enhance biological activity. In some cases, nutrients or fertilizer may be required to maintain the proper microbial environment and lime may be needed periodically for pH control.

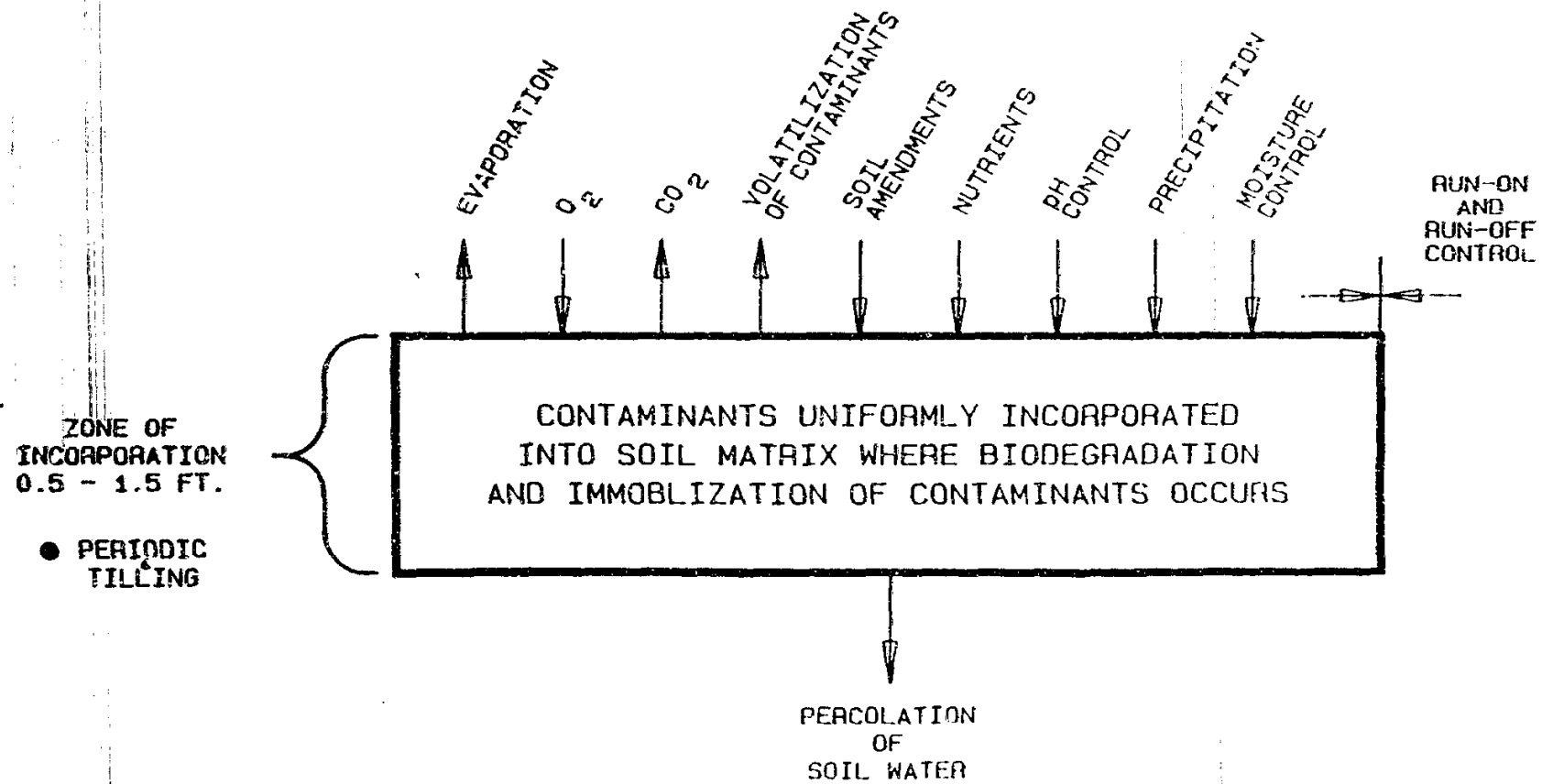
In many situations the foundation of an EBDSSM unit can be a specially prepared soil bed rather than a lined system of some sort. The soil bed is designed to reduce or eliminate downward percolation of excess water to the underlying groundwater by enhancing runoff which is collected and recycled as irrigation water. The unit is designed to prevent precipitation run on so that water moving through and around it can be controlled. The size of an EBDSSM unit can range from a quarter of an acre to ten acres or more. The system is engineered in a manner appropriate for the situation taking into account available land area, the amount of material to be treated and the time frame of treatment.

The viability of EBDSSM soil treatment rests on its capability to reduce the soil concentration of chemicals of interest to acceptable levels through biological and chemical transformations along with controlling emissions, i.e. volatilization and leachate, of chemical compounds from the EBDSSM treatment unit below levels that could cause public health or environmental concern. Using the results of laboratory experiments, in conjunction with transport and fate analysis of particular chemical constituents of the soil, an evaluation of EBDSSM soil treatment can be performed.

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FIGURE 1

KEYSTONE'S EBDSM SOIL TREATMENT UNIT PROCESS SCHEMATIC



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Figure 2 is a schematic diagram of a system to manage impacted soils using EBDSSMSM treatment on site. Soils are excavated and hauled to a biodegradation treatment area located in a portion of the site where it will not interfere with the on-going development. The soil is treated for subsequent use. Two options are shown for on site disposition of treated soils. In one instance the treatment area can be designed to accumulate the soils in layers so that over time the treated soils represent a fill of significant thickness. When all soils are treated, the treatment area is closed and incorporated into the development. Closure may include cover and grading to match final site contours and drainage patterns. This option is particularly suited to fill in a depression on the site or to add elevation to a part of the site. The option requires only one handling of the soils. A second option is to remove a batch of treated soil and use this soil elsewhere as needed. In this manner soil moves through the treatment area in batches rather than being accumulated within the treated area. This option requires an additional handling of the soil, but it can produce a material of construction. The choice between these two disposition alternatives will depend on site characteristics, development plans, the nature of the chemicals and other relevant factors. The criterion for choosing a particular management strategy is to satisfy the relevant risk criteria and the site development plans in a cost effective manner.

PERFORMANCE:

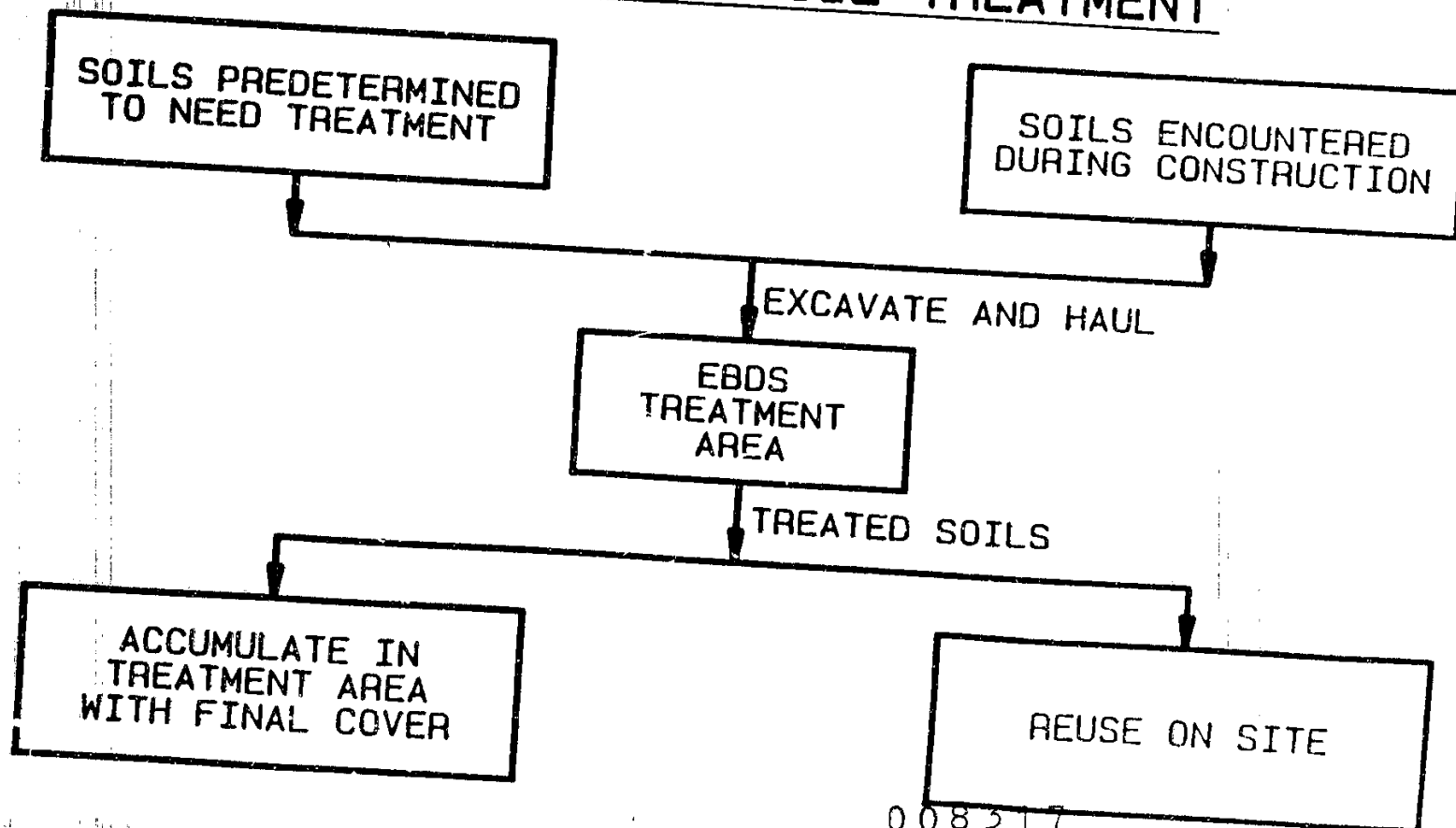
Through extensive bench-scale, pilot-scale and full-scale demonstration testing, Keystone has determined that EBDSSMSM treatment is a technically viable and economically attractive approach for biological degradation of organic materials from petroleum refineries, wood treating facilities, chemical plants and many other industries which have wastes containing chemicals similar to coke/coal tar wastes.

Keystone has installed and is operating a quarter acre EBDSSMSM unit in New Hampshire treating soils from a former wood preserving operation. The soils are contaminated with polynuclear aromatic hydrocarbons (PAHs), pentachlorophenol (PCP) and petroleum hydrocarbons. This unit treats approximately 600 tons of soil in one batch. Temperatures in New Hampshire are such that normally two batches per year can be treated. The objective of this system is to reduce or eliminate the previously listed chemicals in both the soil and the soil-water leachate.

Figure 3 is an engineering drawing showing the plan view of this unit. Shown are the treatment plot, a storm runoff retention pond and a control plot. Contaminated

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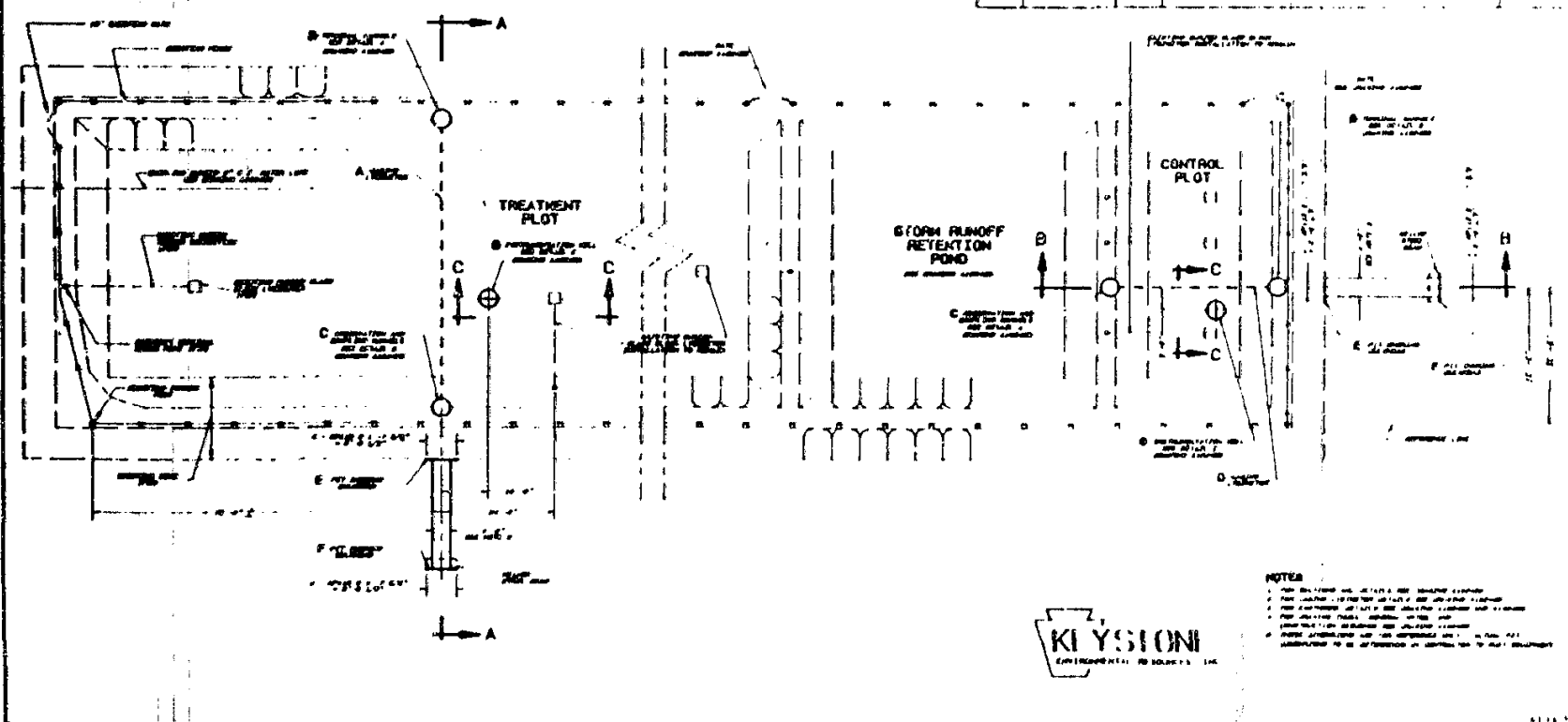
FIGURE 2
SYSTEM FOR ON SITE MANAGEMENT OF SOILS
USING EBDSSM SOIL TREATMENT



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FIGURE 3
ENGINEERED DRAWING OF KEYSTONE'S
ENGINEERED BIODEGRADATION SYSTEM SM
(MODEL 50-200U)

BILL OF MATERIAL				
ITEM	REV. NO.	MARK	DESCRIPTION	QUANTITY
1	1	A	SYSTEM 10' x 10' x 10' - COMPLETE	1
2	1	B	SYSTEM 10' x 10' x 10' - COMPLETE	1
3	1	C	SYSTEM 10' x 10' x 10' - COMPLETE	1
4	1	D	SYSTEM 10' x 10' x 10' - COMPLETE	1
5	1	E	SYSTEM 10' x 10' x 10' - COMPLETE	1
6	1	F	SYSTEM 10' x 10' x 10' - COMPLETE	1
7	1	G	SYSTEM 10' x 10' x 10' - COMPLETE	1



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soil to be treated is hauled into the treatment unit and spread in an approximately 30 cm layer over the entire unit. Amendments are added to provide proper nutrient and pH control. The final grade of the applied soil is sloped to direct runoff within the treatment area towards the storm runoff retention pond. The final slope is set based on soil type to prevent ponding and reduce or eliminate downward percolation while at the same time being gradual enough to control soil erosion. Site soil conditions are such that this particular treatment plot is constructed of prepared soil bed with no liner. Eastern berms are provided around the entire perimeter to control storm water runoff and run on. As one layer of applied soil is treated, a second layer of contaminated soil is placed on top of the treated soil for subsequent biodegradation of soil contaminants.

Storm water from the treatment area is conveyed by gravity to a lined retention pond. The pond is designed to contain storm runoff from the treatment plot corresponding to a 25 year 24 hour storm event. Collected water is reused on the treatment plot as needed for moisture control. Supplemental water is also available when needed.

The particular engineering design given also shows a control plot. This plot was constructed and used for quality assurance/quality control (QA/QC) purposes. The control plot was not loaded with contaminated soil, but was operated and monitored in the same manner as the treatment plot and thus served to provide background conditions. Operation and monitoring of the control plot was only carried out during one treating cycle after which time the capabilities of the EBDSSM soil treatment process were demonstrated.

EBDSSM soil treatment is very effective in reducing biodegradable organic contaminants in soil. As evidenced by the data given in Table 1, over two years of soil treatment with multiple treating cycles at the New Hampshire site achieved 85 percent reduction in freon extractables, a measure of hydrocarbons present, 73 percent reduction in pentachlorophenol and 87 percent reduction in total polynuclear aromatic hydrocarbons (PAH). The more soluble PAHs generally achieve better reductions than the less soluble PAHs. Hence, even though PAHs are still detectable, they are not very mobile due to limited solubility in water.

The potential for leaching is assessed by the Toxicity Characteristics Leaching Procedure (TCLP). This test mixes water and solids under controlled conditions for a specific time period, after which the water is analyzed for chemicals. Typical TCLP results from the New

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Ex Situ Treatment
Engineered BioDegradation SystemSM

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TABLE 1
KEYSTONE'S EBDsSM SOIL TREATMENT PROCESS
PERFORMANCE HIGHLIGHTS

Chemical Parameters	Aqueous Solubility (ug/l)	Untreated Soil Avg. Conc. (mg/kg-dry weight)	Treated Soil Avg. Conc. (mg/kg-dry weight)	Percent Reduction
Freon Extractables	-	7235	1103	85
Petroleum Hydrocarbons	-	2227	680	69
Pentachlorophenol	-	67	18	73
<u>Polynuclear Aromatic Hydrocarbons</u>				
Naphthalene	31700	858	20	98
Acenaphene	3930	314	19	94
Acenaphthylene	-	25	< 1.0	96
Anthracene	73	1360	385	72
Fluorene	1980	471	53	89
Phenanthrene	1290	1030	82	92
Benzo (a) anthracene	14	106	8	92
Chrysene	2	89	13	86
Fluoranthene	260	613	34	95
Pyrene	135	503	24	95
Benzo (k) fluoranthene	-	15	4	72
Benzo (a) pyrene	3.8	23	9	61
Benzo (b) fluoranthene	-	33	17	49
Dibenz (a,h) anthracene	2.49	12	11	-
Indeno (1,2,3-c,d) pyrene	-	< 11.2	4	-
Benzo (g,h,i) perylene	0.26	11.3	11	-
Total PAH	-	5472	695	87

Note: Data represents two month treating cycle. Depending upon site specific conditions and specific operations, further reductions may be achievable.

Less than values represent detectable concentrations.

Hampshire EBDSSM soil treatment process for untreated and treated soils are given in Table 2. The more soluble PAHs are detectable in TCLP extracts of untreated soil and below detection in treated soil. Furthermore, EBDSSM soil treatment monitoring at Nashua showed no detectable migration of soil contaminants into the subsurface soil zone and no soil contaminants detected in downgradient monitoring wells.

EBDSSM soil treatment also accounts for fugitive air emissions. Dust is controlled by keeping the soil wet as needed for proper moisture control to allow for biological activity. Volatilization of soil contaminants is controlled through properly designed loading applications and tilling cycles.

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Ex Situ Treatment
Engineered BioDegradation SystemSM

TABLE 2
KEYSTONE'S EBDSM SOIL TREATMENT PROCESS
TYPICAL TCLP EXTRACT PAH CONCENTRATIONS OF UNTREATED AND TREATED SOIL

Chemical Parameters	Aqueous Solubility (ug/L)	TCLP Before Treatment (mg/L)	TCLP After Treatment (mg/L)
Naphthalene	31700	1.61	<0.001
Acenaphthene	3930	0.213	<0.0005
Acenaphthylene	-	0.052	<0.0005
Anthracene	73	0.018	<0.0005
Fluorene	1980	0.159	<0.0005
Phenanthrene	1290	0.155	<0.0005
Benzo (a) anthracene	14	0.00008	<0.0005
Chrysene	2	<0.00015	<0.0005
Fluoranthene	260	0.0086	<0.0005
Pyrene	135	0.0063	<0.0005
Benzo (k) fluoroanthene	-	<0.00002	<0.0005
Benzo (a) pyrene	3.8	<0.00002	<0.0005
Benzo (b) fluoranthene	-	<0.00002	<0.0005
Dibenz (a,h) anthracene	2.49	<0.00003	<0.0005
Indeno (1,2,3-c,d) pyrene	-	<0.00005	<0.0005
Benzo (g,h,i) perylene	0.26	<0.00005	<0.0005

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Note: Less than values represent detectable concentrations.

INCINERATION (Ex Situ Treatment)

MEDIUM:

All waste forms except large items which cannot be easily reduced in size to fit normal incineration equipment. Contaminated groundwater or surface water are not logical candidates.

PROCESS TYPE:

Thermal

RELATED SITE EXPERIENCE:

Petroleum industry, wood treating industry, coke and coal tar distillation industry, manufactured gas plants, chemical plants and other industries.

APPLICABLE CHEMICALS OF INTEREST:

All organic chemicals of interest, ammonia and sulfur containing inorganics. Metals are not treated.

TECHNOLOGY STATUS:

Established technology for the treatment of industrial hazardous wastes. Bench-scale, pilot-scale, full-scale.

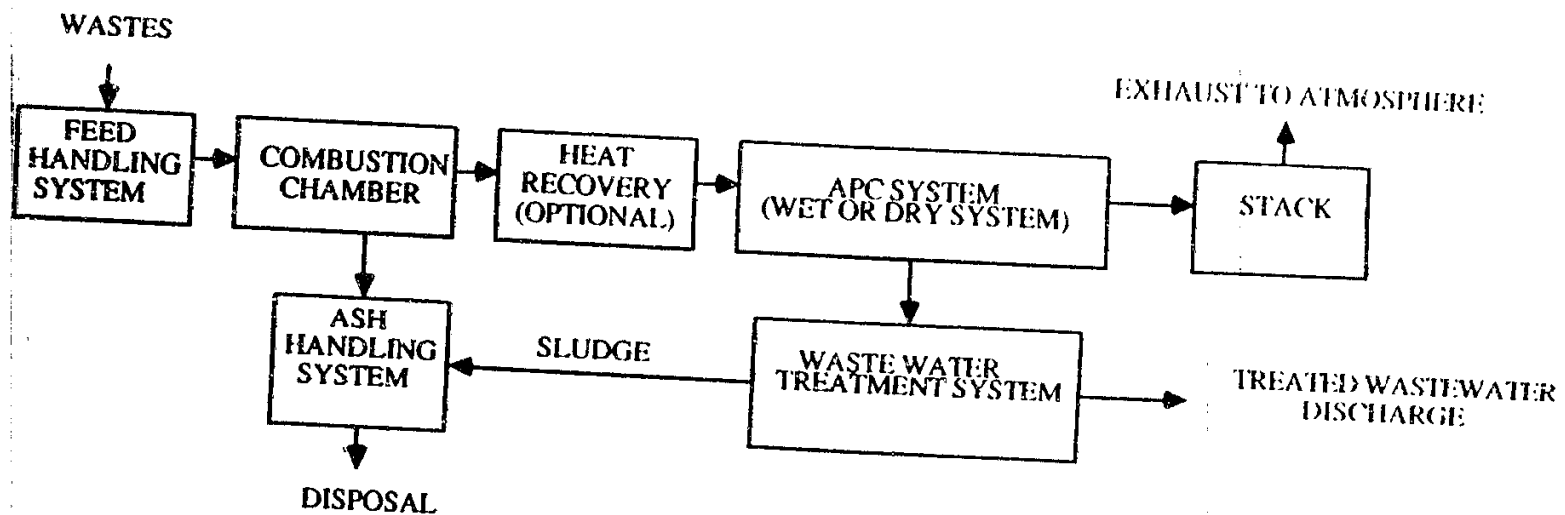
DESCRIPTION:

Incineration nominally refers to the high temperature oxidation of organic wastes, although incinerators can be designed to treat contaminated water, soil and debris. The basic incinerator process components typically include a primary and secondary combustion chamber followed by an air pollution control system. The wastes are fed to a primary incinerator and the organics are volatilized into the gas phase and either pyrolyzed (in starved air environments) or oxidized (in the presence of air) to simpler combustion products such as CO_2 , H_2O , HCl and SO_2 . Nitrogen containing compounds, i.e. NO_x , may also be formed from combustion of nitrogen-containing organics or cyanides or fixation of nitrogen in air. Liquid wastes can often be incinerated completely using a single high temperature combustion chamber. For solid or sludge wastes, a higher temperature secondary combustion chamber (SCC) is usually required after the primary combustion chamber to ensure complete destruction of all volatilized organics that might remain in the primary combustion fuel gas.

A general schematic flow diagram of the basic system components for a conventional incineration system is given in Figure 1. This system is described below.

Feed system - The principal functions of the solids materials handling and feed systems are: (1) to alter the solid waste physical characteristics by shredding/crushing, screening and blending so the

FIGURE 1
SCHEMATIC BLOCK FLOW DIAGRAM OF AN INCINERATION SYSTEM



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materials can be fed into the thermal treatment system, and (2) to provide an inventory of feed materials. Dewatering is recommended if the wastes contain more than 50 percent water.

Thermal Processing Equipment - Thermal processing equipment typically consists of a primary and secondary device, although some systems use a single unit operation, e.g. most fluid bed and all liquid incinerators. The primary chamber may be operated in either an oxidative or pyrolytic (starved air) mode or may function as a thermal desorber to vaporize and separate contaminants from the nonvolatile inert solids. The off-gas from the primary chamber is typically combusted under oxidative conditions in a secondary combustion chamber.

Ash Handling Equipment - Ash treatment systems may include: (1) adding water to cool the ash and minimize potential dust problems, (2) cooling the ash by exchanging heat with either air or water, or (3) storing the ash until it can slowly cool by natural radiation and convection. Heavy metals are mostly concentrated in the ash and must be analyzed to determine if the leachable metal concentrations exceed EPA toxicity levels.

Heat Recovery - Energy recovery is an important economic consideration for large fixed-base facilities, particularly if auxiliary fuel requirements are high and there is a readily available outlet for the steam (and/or electricity) which can be produced.

Air Pollution Control (APC) Equipment - Three types of APC systems are commonly used: wet systems, dry systems and acid gas neutralization. Dry systems are usually more efficient than wet systems.

APC Process Residue Treatment - All types of APC systems will generate a "by product" or "blowdown" which will require treatment and/or disposal. Wet scrubbing systems produce an aqueous effluent (purge) stream that may require pH adjustment, heavy metals removal and/or suspended solids removal before disposal. The dry in situ systems produce solid salt residues during the acid gas neutralization step. These salts are collected in a cyclone and baghouse and must be disposed of.

PERFORMANCE:

Treatment efficiency as measured by Destruction Removal Efficiency (DRE) has been measured as >99.99 percent for various hazardous organic chemicals. Specific DRE data for chemicals of interest are not available. Performance of on-site incineration has not

been well demonstrated, although treatment efficiency for chemicals of interest other than metals is expected to be adequate to meet any regulatory criteria.

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SOIL WASHING (Ex Situ Treatment)

MEDIUM:

Contaminated soils or solids (e.g. debris).

PROCESS TYPE:

Physical

RELATED SITE EXPERIENCE:

Wood treating industry, coke and coal tar distillation industry.

APPLICABLE CHEMICALS OF INTEREST:

Water soluble compounds of interest (phenols) are most applicable. Compounds having reasonable water solubility (aromatics, naphthalene) may be applicable. PAHs could be applicable if surfactants or organic solvents can be used. Metals and insoluble cyanide salts are potentially extractable using acid or chelant aqueous wash.

TECHNOLOGY STATUS:

Developing technology that has been primarily demonstrated in the laboratory. Bench-scale, pilot-scale. Established technology in the coal mining industry.

DESCRIPTION:

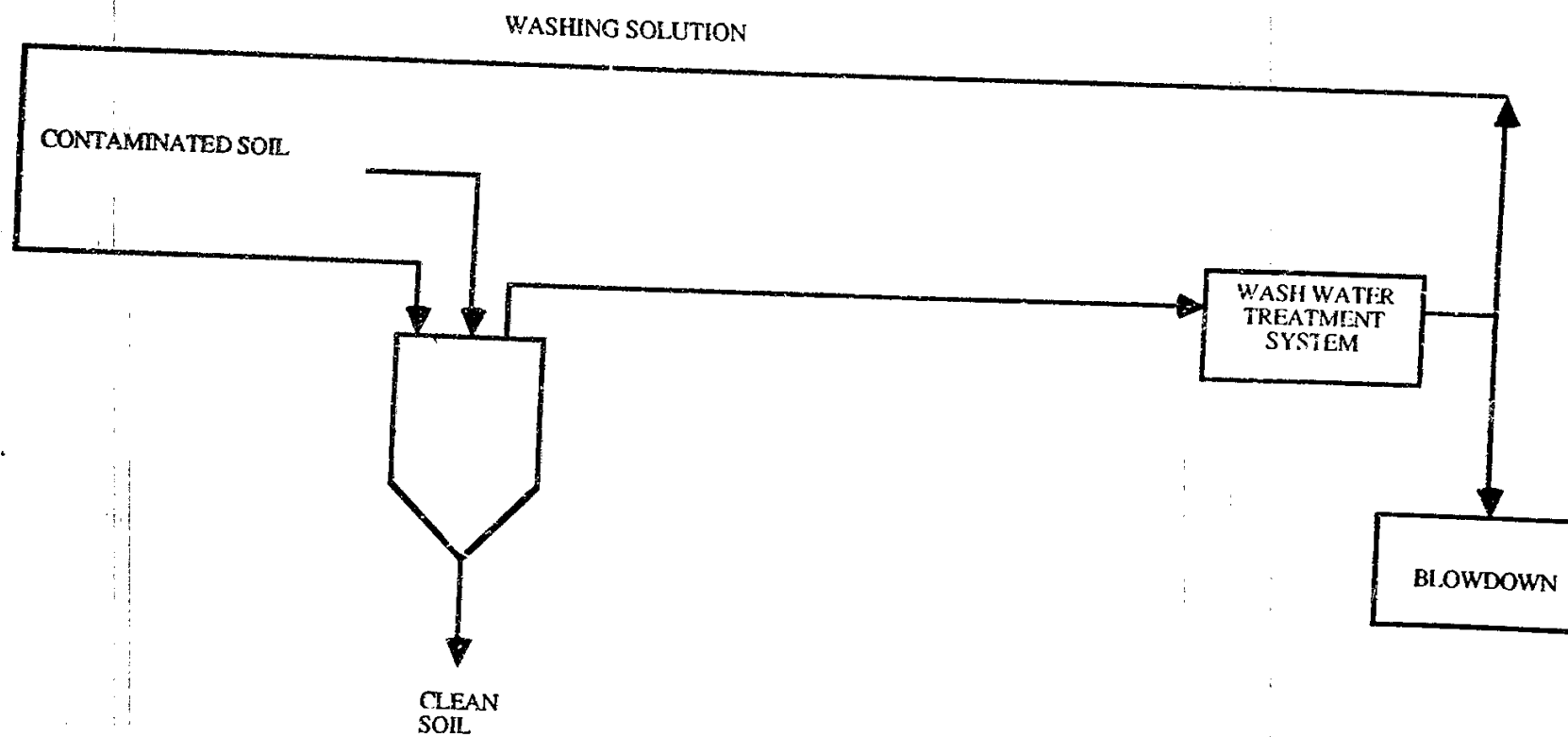
Soil washing is a physical separation procedure for detoxifying contaminated soil that involves the washing of contaminants from the soil (or other inert solids) into a liquid medium. This technique can be carried out in equipment that is designed for contacting excavated soil with the liquid, or the washing can be carried out in situ by applying or injecting the liquid into contaminated soil. After contact with the soil, the washing solution is treated for removal of the contaminants and then recycled for additional soil washing. In some cases multiple washings are required to reduce the contaminant concentration to acceptably low levels. For cleanups involving excavations, the decontaminated soil is redeposited in the excavation area.

Figure 1 represents a schematic of a full-scale soil washing system in which the contaminated solid materials are charged to the unit in conjunction with the washing solution. Based on the soil cleanup requirements, multiple washing cycles may be necessary. The cleaned solid materials can subsequently be discharged back to the site. The washing solution can be reused in the process or discharged to a wastewater treatment plant for necessary treatment.

Generally, contaminants are held on the solid surface by

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FIGURE 1
SOIL WASHING SCHEMATIC DIAGRAM



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one or more physical/chemical phenomena. The mechanisms responsible for holding contaminants are entrapment, adsorption and chemical reactions. Entrapment and adsorption occurs when contaminants cannot become/remain soluble and have taken up the available adsorption sites of the solid surface. The contaminants are simply trapped on the solid surface but can be removed by physical separation equipment used in the soil washing process.

PERFORMANCE:

Bench scale soil washing testing performed by Keystone on solid materials obtained from various wood treating facilities indicates that PCP removal up to 100%, total PAHs (creosote compounds) removal up to 95% and oil and grease removal up to 99% can be achieved. However, site specific conditions may impact on the removal efficiency that can be achieved for the chemicals of interest. Therefore site specific conditions need to be considered to properly implement this technology.

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STABILIZATION
(Ex Situ Treatment)

<u>MEDIUM:</u>	Sludges; potentially solid residues and contaminated soils.
<u>PROCESS TYPE:</u>	Chemical/physical
<u>RELATED SITE EXPERIENCE:</u>	Petroleum industry, wood treating industry, chemical industry.
<u>APPLICABLE CHEMICALS OF INTEREST:</u>	Metals, CN. Low concentrations of organic chemicals of interest.
<u>TECHNOLOGY STATUS:</u>	Established technology with changing modifications. Bench-scale, pilot-scale, full-scale.
<u>DESCRIPTION:</u>	<p>Stabilization refers to treatment processes which are intended to modify the characteristics of wastes or contaminated materials to facilitate handling and disposal and decrease the potential for release of pollutants.</p> <p>The process operation can take place in situ, on site using transportable process equipment, or at a fixed based disposal facility. Equipment requirements are largely determined by the type of mixing employed. All systems consist of the following steps:</p> <ul style="list-style-type: none">o Mixing the waste with the treatment ingredients,o Allowing time for the absorption, gelling reaction, or curing to take place ando Disposition of the solidified product. <p>In situ mixing is primarily suitable for the closure of liquid or slurry holding ponds or lagoons. Although site closures have been done using standard earth-moving equipment, such as bulldozers and backhoes to mix the solidifying ingredients into the waste, specialized equipment has been developed by some vendors whereby the solidifying ingredients are fed, injected and mixed into the waste by pneumatic vibrating "fingers". The mixture is allowed to cure and remain in place. The pond is closed in stages. Solidification is first done near a bank and when the waste is cured to an adequate compressive strength, the equipment is moved onto the treated area and another section is then solidified. An</p>

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**Ex Situ Treatment
Stabilization**

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alternative in-place technique, the JST Method which is to be tried at a Superfund site, uses a giant auger to loosen and blend the soil with stabilization agents, with the process being repeated in adjacent locations until the entire contaminated soil volume is treated (Hazardous Waste Consultant, 1987). Quality control can be a problem with in-place mixing.

On-site mixing is primarily used for site cleanup and closure of waste ponds or contaminated solids. Many stabilization vendors today have specialized mobile mixing plants that can be brought readily to the site adjacent to the waste. Otherwise conventional/mortar mixing equipment or pugnill systems can be assembled. The waste is conveyed to the mobile unit and mixed with the solidifying ingredients and then is usually discharged to a nearby specially prepared area for curing prior to placement in a landfill or vault on site or transferred off site. Materials handling is a major factor in performing stabilization. Wastes before and immediately after treatment are often pumpable and can be conveyed to and from the mixer by pipeline. Otherwise, dredging equipment and trucks or mobile containers are used. Contaminated soils must be handled using solids-transfer equipment. The size of solids which can be transferred and mixed will be limited depending on the type of system.

PERFORMANCE:

Performance has traditionally been determined by measuring the concentration of EPA designated contaminants in an aqueous extract of a treated waste sample. Various vendors practicing stabilization have reported concentration of metals can be as low as EPA drinking water standards for suitable wastes and stabilization formulations. Wastes containing organics have been stabilized to result in significant reduction in leached organic contaminants. Test data for basically inorganic sludges containing low levels of PAH have shown less than 1 ppb PAH in extract. Performance as determined by achieving a solid material (no free liquid) with characteristics suitable for placement in a landfill has been demonstrated on inorganic and organic sludges. Performance is very waste-dependent and formulations to successfully "fix" organics are specialized. Performance as measured by long term stability of the contaminants in a landfill environment is not well documented.

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THERMAL DESORPTION (Ex Situ Treatment)

MEDIUM:

Soils, sediments and sludges.

PROCESS TYPE:

Thermal/physical separation

**RELATED SITE
EXPERIENCE:**

None

**APPLICABLE
CHEMICALS OF
INTEREST:**

All organic chemicals of interest and cyanide.

**TECHNOLOGY
STATUS:**

Emerging technology for treating wastes or contaminated solids. Previously utilized for chemical manufacturing and incineration of sludges and soils. Bench-scale, limited pilot-scale and limited full-scale.

DESCRIPTION:

Thermal desorption refers to the separation of chemical constituents that can be volatilized from nonvolatile solids, such as soil. It requires heating the solid to elevate the vapor pressure of the chemical to enable diffusion through and volatilization from the waste in a reasonable time. Desorption temperatures are lower, and in most cases much lower, than the temperature required for thermally induced decomposition reactions, e.g. oxidation and pyrolysis, to occur. This distinguishes thermal desorption from incineration, in which combustion (destruction) of the contaminants is intended. A schematic diagram of a typical thermal desorber system is presented in Figure 1.

Thermal desorption can be coupled with incineration to destroy the volatilized constituents. On the other hand, alternative process techniques can be used for collecting the volatilized constituents. In this case, the process serves as a volume reduction technique, concentrating the contaminants in a very small volume, which facilitates disposal or treatment and provides the opportunity in certain cases for recovery/reuse.

Thermal desorption can be performed in a variety of types of equipment which can provide adequate heat transfer and vapor release. As with incineration of soils or sludges, the total heat required is a function of the amount of moisture, and to a lesser extent organic content of the solid (soil), and the temperature that must be achieved. Indirect heat transfer is preferred since the quantity of desorber off-gas is much lower than for direct heating options, either direct fired, e.g. kiln, or those using hot gas, e.g. fluid bed. In fact, for desorption

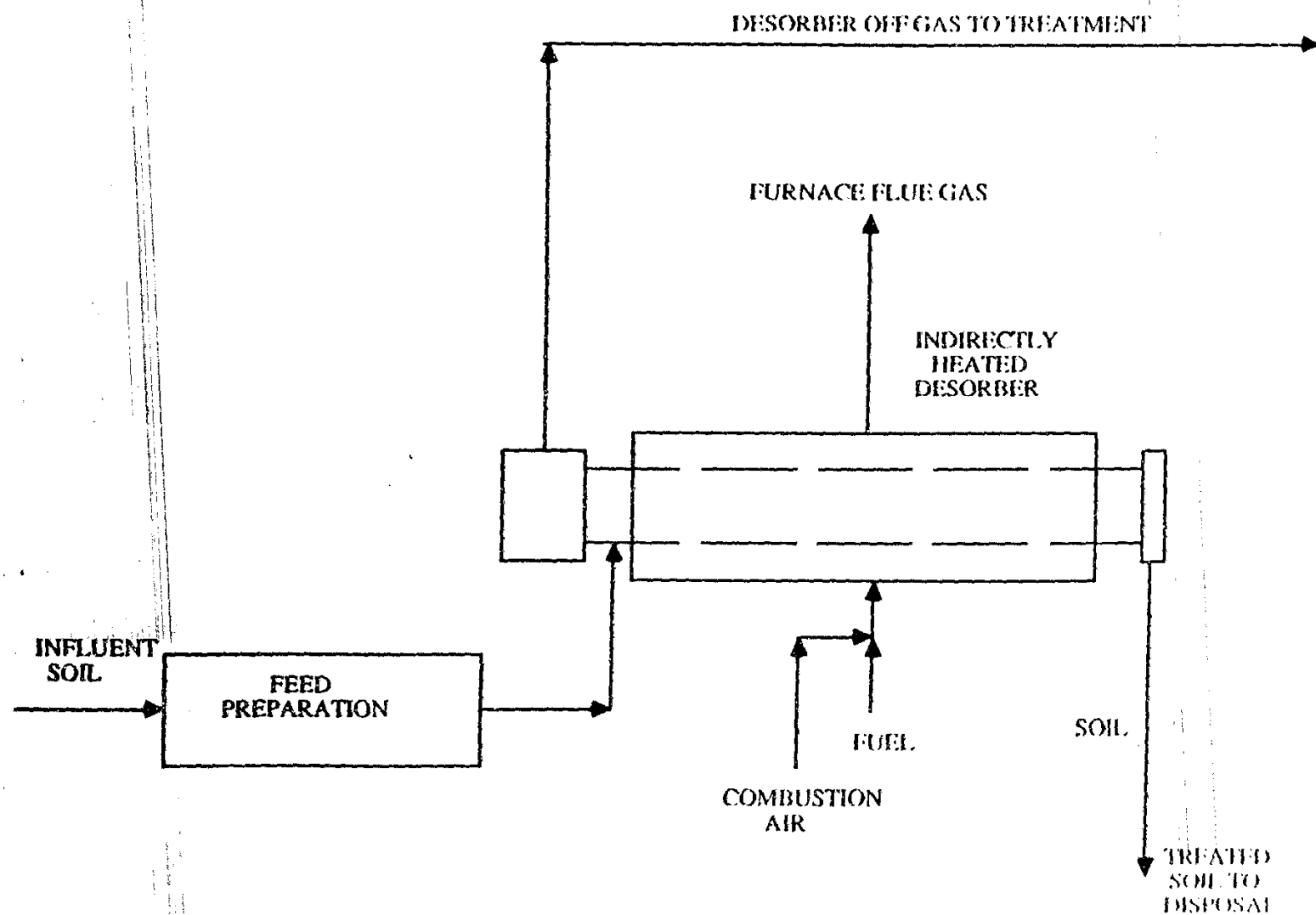
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**Ex Situ Treatment
Thermal Desorption**

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FIGURE 1
THERMAL DESORBER SCHEMATIC DIAGRAM



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systems that employ off-gas treatment/collection processes rather than incineration, the volume of process emissions is so low that the total system might be considered "closed". The choice of desorber for treating a particular contaminated solid depends on the required desorption temperature and the physical characteristics of the solid. Maximum solids temperatures required may range from 150 to over 500°C. Volatile organic solvents can be desorbed using steam as a heat source; less volatile materials require higher temperature heat transfer fluids or a furnace.

PERFORMANCE:

A large fixed-base facility has been used for treating contaminated soils from abandoned coal gasification plants as well as other contaminated soils in the Netherlands. This unit, designed, built and operated by Ecotechniek, has been operating since 1983. It uses an indirectly heated rotary desorber with an oil-fired fume incinerator for off-gas treatment. PAH levels have been reduced from over 1,000 ppm to less than 1 ppm; total benzene, toluene, xylene, and naphthalene have been reduced from 100 ppm to less than 1 ppm; cyanides have been reduced from 80 ppm to less than 1 ppm. Higher treatment efficiencies could have been achieved with more rigorous desorption conditions. A pilot-scale study of coal gasification plant soils was conducted by another Netherlands firm which followed extensive laboratory treatability tests. Cyanide levels were reduced at 2 ppm at 300°C desorption temperatures, whereas PNAs were reduced to less than 10 ppb, the analytical detection limit. This pilot unit consisted of an indirectly heated rotary desorber followed by a fume incinerator.

Pilot-scale tests have also been conducted by several firms at different sites. Table 1 summarizes these tests. Laboratory testing by IT of sludge from a wood-treatment site demonstrated PAHs were reduced from >10,000 pp, to nondetectable levels (<2 ppm).

3.4 OFF-SITE SOIL/RESIDUE TREATMENT
INCINERATION (SEE SECTION 3.3)

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4.1 OFF-SITE WATER DISPOSAL
INDUSTRIAL TREATMENT WORKS
POTW
NPDES

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INDUSTRIAL TREATMENT WORKS (Discharge)

MEDIUM: Raw and untreated groundwater, surface waters and process wastewaters.

PROCESS TYPE: Discharge to a permitted industrial treatment works.

RELATED SITE EXPERIENCE: Wood treating industry, coke and coal tar distillation industry, chemical plants and other industries.

APPLICABLE CHEMICALS OF INTEREST: All chemicals of interest provided that the receiving treatment works can handle the particular wastewater.

TECHNOLOGY STATUS: Established alternative. Full-scale.

DESCRIPTION: This option involves the transport of contaminated wastewater to industrial facilities which are capable of providing the type of treatment required for restoration. A typical example is the DuPont treatment works located near Philadelphia, Pennsylvania. DuPont operates a large scale activated sludge system which uses powdered activated carbon in its process. This system, which has a capacity that exceeds the treatment demands of Dupont, accepts wastewater for treatment on a surcharge basis.

If an acceptable industrial treatment facility is not available on or adjacent to the site, the primary regulatory considerations for this option would be transportation regulations under the U.S. Department of Transportation or the states. The major factors governing the transportation of liquids include classification, i.e. hazardous or nonhazardous, quantity, composition and method and route of shipment.

Additionally, if a wastewater is RCRA hazardous, a manifest system must be followed during shipment. Relevant U.S. Department of Transportation regulations can be found in the Code of Federal Regulations (49 CFR).

Other factors which must be considered include pretreatment considerations, surcharge fees and other economic considerations, volume and duration, health and risk assessment considerations, and technical and economic alternatives.

PERFORMANCE: Accepted industrial practice when economically

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**Discharge
Industrial Treatment Works**

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justified. Performance data are not presented due to the specific nature of each particular application.

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2

**Discharge
Industrial Treatment Works**

**POTW
(Discharge)**

MEDIUM:

Raw and treated groundwaters, surface waters and process wastewaters.

PROCESS TYPES:

Discharge according to the permit requirements of the particular Publicly Owned Treatment Works (POTW).

**RELATED SITE
EXPERIENCE:**

Petroleum industry, wood treating industry, coke and coal tar distillation industry, manufactured gas plants, chemical plants and other industries.

**APPLICABLE
CHEMICALS OF
INTEREST:**

All chemicals of interest provided that pretreatment limitations can be economically achieved.

**TECHNOLOGY
STATUS:**

Established alternative with increasing applications due to increasingly more stringent NPDES requirements. Pilot-scale, full-scale.

DESCRIPTION:

Publicly Owned Treatment Works (POTW) are used for domestic wastewater treatment as mandated by the Clean Water Act of 1977. These systems typically consist of several wastewater treatment processes, depending on the degree of treatment required. The EPA was mandated by the Clean Water Act to establish pretreatment standards to control the introduction of industrial pollutants into POTWs. These regulations are termed pretreatment standards and can vary for different POTWs. States and local municipalities have also been given authorization by the EPA to establish limits for discharge of wastewater to these POTWs, but these regulations must, at a minimum, be equivalent to Federal regulations. The more stringent of the Federal and state regulations usually apply to the discharged wastewater. Amendments to the Clean Water Act have been issued as recently as 1987 and can be expected to be amended further in the future. For MGP sites, the pretreatment of wastewater may be required prior to its discharge to a POTW.

Regulations governing discharges to POTWs depend on the effluent standards that the POTW must meet, the treatment capabilities of the POTW and the demand (hydraulic and pollutant) on the facility. All treatment works must obtain a National Pollution Discharge Elimination System (NPDES) permit. Based on this permit, the governing authority of the treatment works (usually a city or county government) establishes criteria

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with which users of the system must comply.

Other considerations regarding the use of POTWs for discharge of wastewater include economics, e.g. transportation and basic service, POTW process constraints and attitude of the local authorities (and public) towards wastewaters discharges to the POTW.

PERFORMANCE:

Full-scale data regarding POTW co-treatment of wastewaters contaminated with chemicals of interest are not available. However, data from a pilot-scale study in which the co-treatment of groundwaters from a MGP site with a typical POTW influent (municipal wastewater) was evaluated indicates that the addition of slightly to moderately contaminated wastewaters at a fraction (up to 20%) of the total wastewater flow should result in non-measurable effects in terms of activated sludge treatment performance and non-significant effects in terms of treated discharge quality.

008340

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**NPDES
(Discharge)**

MEDIUM:

Raw and treated groundwaters, surface waters and process wastewaters.

PROCESS TYPE:

Discharge according to a National Pollution Discharge Elimination System (NPDES) permit.

**RELATED SITE
EXPERIENCE:**

Petroleum industry, wood treating industry, coke and coal tar distillation industry, chemical plants and other industries.

**APPLICABLE
CHEMICALS
OF INTEREST:**

All chemicals of interest provided that discharge limitations can be economically achieved.

**TECHNOLOGY
STATUS:**

Established alternative but increasingly more stringent permit requirements have reduced its applicability. Full-scale.

DESCRIPTION:

This option requires a permit from the EPA that will allow for the discharge of wastewater to a receiving body of water (e.g., river, lake). These permits require that the wastewater discharge meet certain quality criteria guidelines which are usually very stringent. Pursuance of a National Pollution Discharge Elimination System (NPDES) permit is typically conducted only when discharge to a POTW cannot be obtained. Conditions that could require the need of an NPDES permit include:

- o No available sewer hook up with a POTW or no available industrial treatment facility,
- o An unwillingness of POTW personnel to issue a permit and/or an unwillingness of neighboring industrial facilities to accept offsite wastewaters and
- o The discharge of a wastewater that will exceed (hydraulically or otherwise) the limitations of the POTW.

The Federal Clean Water Act as amended in 1987 provides the EPA with the authority to require a NPDES permit for any discharge of wastewater to a receiving body of water. This would include injection or land application if the discharge could contaminate a shallow aquifer or local surface waters. Additional

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**Discharge
NPDES**

008341

regulations as specified by the Coastal Zone Management Act may also need to be considered for coastal areas.

The criteria established in an NPDES permit can vary significantly from one location to another. In most cases the limits are negotiable. However, obtaining an NPDES permit can be a lengthy process. Other factors which must be considered for this option include economic considerations, pretreatment requirements and proximity of the receiving body of water.

PERFORMANCE:

Accepted industrial practice where discharge limitations can be economically achieved. Required performance is determined on a case by case basis by the regulatory agency which regulates the specific discharge. Performance data are not presented due to the specific nature of each particular application.

008342

4.2 ON-SITE SOIL/RESIDUE DISPOSAL
ON-SITE LANDFILL

008343

**ON SITE LANDFILL
(Ex Situ Containment)**

MEDIUM:

All solid waste residues, contaminated soil or other contaminated solid materials

PROCESS TYPE:

Storage

RELATED SITE EXPERIENCE:

Past practice (without currently required engineering and management controls)

APPLICABLE CHEMICALS OF INTEREST:

Theoretically, all chemicals of interest if contained in a solid matrix could be considered for "interim" or long term storage using a landfill. Current regulations restrict use of landfills based on free liquid content and toxicity of chemicals.

TECHNOLOGY STATUS:

Established Technology with changing modifications.

DESCRIPTION:

A secure landfill is a facility which provides long term isolation of waste materials while minimizing the release of contaminants to the environment. Secure landfills are designed to limit the release of leached contaminants into the groundwater, runoff to surface waters and dispersion into the air. As regulatory requirements have become more restrictive, the design criteria for landfills have become increasingly stringent. Secure landfills are used for disposal of a wide variety of solid and semi-solid materials. Recent regulations have placed restrictions on the type of waste materials which may be placed in landfills. Materials may be prohibited on the basis of liquid content, reactivity and/or the presence of highly toxic or unstable materials.

Newly-constructed or existing landfills are applicable for the disposal of wastes and contaminated soils excavated as part of site cleanup and partial or complete removal actions. These facilities have low permeability liners, leachate collection systems and leak detection zones. They also have low permeability caps that encapsulate the waste and prevent any migration of wastes from the landfill.

Variations of this design may satisfy the requirements of RCRA, but should include the following as a minimum:

- o Cap
- 2 feet of cover soil suitable for vegetation

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- Infiltration zone permeability of at least 10^{-3} cm/sec
- 2 feet of low permeability material; permeability less than 10^{-7} cm/sec
- Synthetic membrane

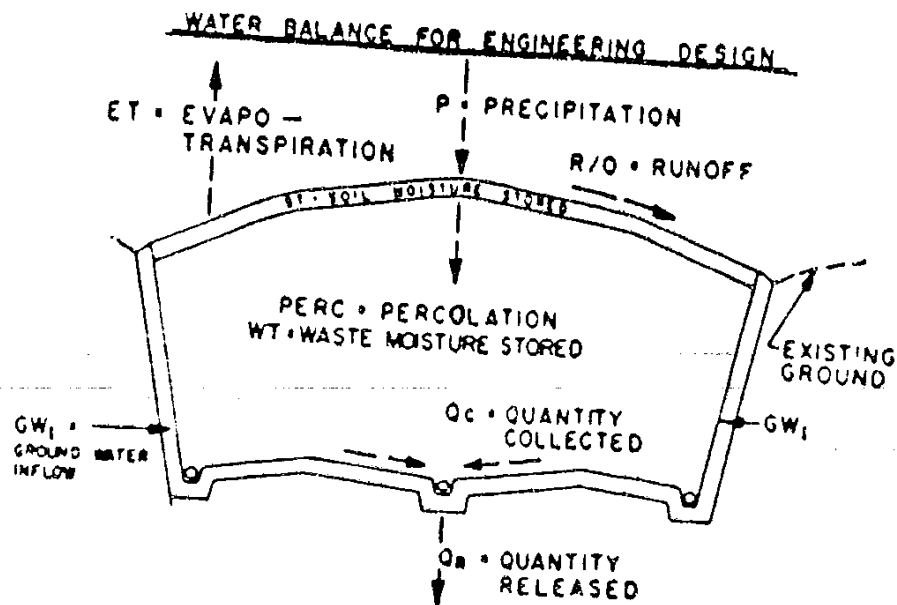
o Liner

- Leachate collection zone permeability of at least 10^{-3} cm/sec
- Leachate detection zone; permeability of at least 10^{-3} cm/sec
- 2 feet of low permeability material; permeability less than 10^{-7} cm/sec

PERFORMANCE:

On-site landfills are effective techniques for disposal of contaminated materials, but there is still the possibility that the material would need to be removed to a permanent facility in the future. Monitoring would have to be performed on a continual basis to assure that the material is still contained and not contaminating the groundwater. This would add to the maintenance and operating costs of the site. On-site landfills can be implemented as a temporary solution to immediate problems of containment.

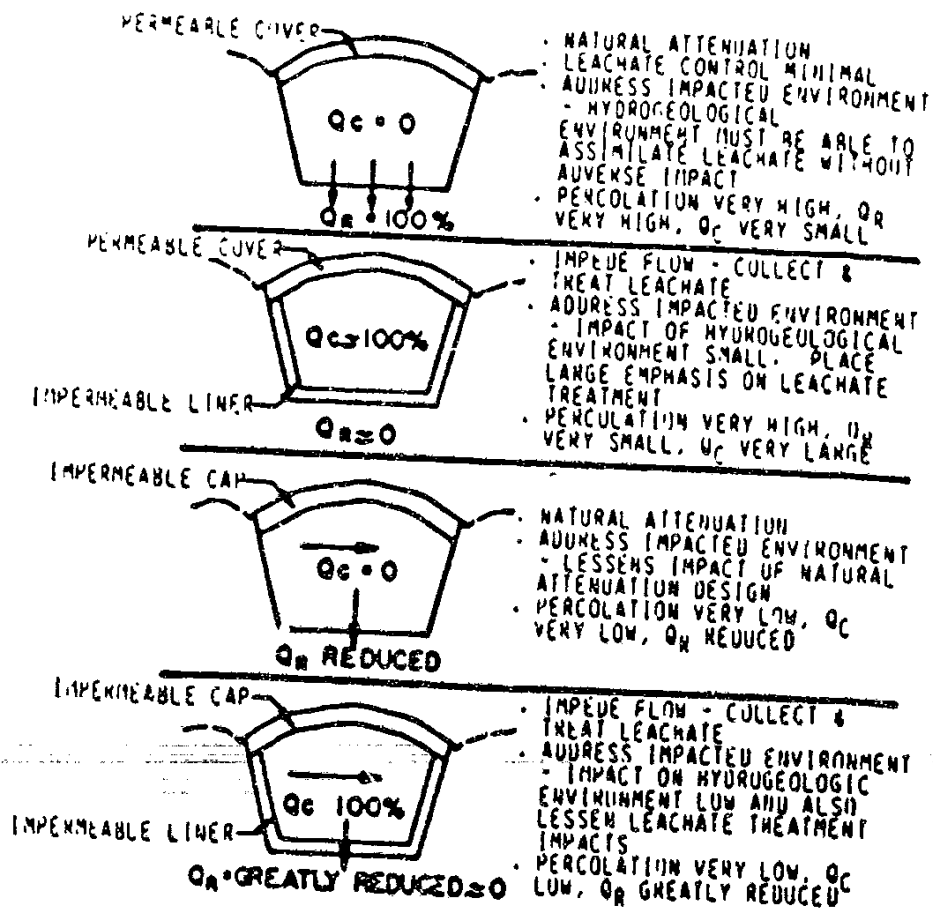
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MASS BALANCE

$$PERC + GW_1 - WT + Q_c + Q_r$$

Figure 2.19. Moisture components of landfills (Smith, 1983).



Four combinations of capping and liners (Smith, 1983).

008346

4.3 OFF-SITE SOIL RESIDUE DISPOSAL
OFF-SITE LANDFILL

008347

**OFF SITE LANDFILL
(Ex Situ Containment)**

MEDIUM:

All solid waste residues, contaminated soil or other contaminated solid materials

PROCESS TYPE:

Storage

**RELATED SITE
EXPERIENCE:**

Past practice (without currently required engineering and management controls).

**APPLICABLE
CHEMICALS OF
INTEREST:**

Theoretically, all chemicals of interest if contained in a solid matrix could be considered for "interim" or long term storage using a landfill. Current regulations restrict use of landfills based on free liquid content and toxicity of chemicals

**TECHNOLOGY
STATUS:**

Established Technology with changing modifications

DESCRIPTION:

A secure landfill is a facility which provides long term isolation of waste materials while minimizing the release of contaminants to the environment. Secure landfills are designed to limit the release of leached contaminants into the groundwater, runoff to surface waters and dispersing into the air. As regulatory requirements have become more restrictive, the design criteria for landfills have become increasingly stringent. Secure landfills are used for disposal of a wide variety of solid and semi-solid materials. Recent regulations have placed restrictions on the type of waste materials which may be placed in landfills. Materials may be prohibited on the basis of liquid content, reactivity and/or the presence of highly toxic or unstable materials.

Newly-constructed or existing landfills are applicable for the disposal of wastes and contaminated soils excavated as part of site cleanup and partial or complete removal actions. These facilities have low permeability liners, leachate collection systems and leak detection zones. They also have low permeability caps that encapsulate the waste and prevent any migration of wastes from the landfill.

Variations of this design may satisfy the requirements of RCRA, but should include the following as a minimum:

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**OFF SITE LANDFILL
(Ex Situ Containment)**

008348

- o Cap
 - 2 feet of cover soil suitable for vegetation
 - Infiltration zone permeability of at least 10^{-3} cm/sec
 - 2 feet of low permeability material; permeability less than 10^{-7} cm/sec

 Synthetic membrane

- o Liner
 - Leachate collection zone permeability of at least 10^{-3} cm/sec
 - Synthetic membrane
 - Leachate detection zone; permeability of at least 10^{-3} cm/sec
 - 2 feet of low permeability material; permeability less than 10^{-7} cm/sec

Off site disposal involves the excavation and removal of waste piles, contaminated soils and the transport of these materials to a suitable hazardous waste disposal facility. Under CERCLA, off site disposal will not require a permit for hazardous waste transport; however, licensed transporters are required to haul the material to a RCRA-permitted facility.

PERFORMANCE:

Preliminary estimates indicate that off site disposal may be cost effective when dealing with small volumes of material. Off site disposal would essentially eliminate any long term effects of the contaminants to the site area. Short term effects might be more pronounced, however, because of the public health and environmental risks associated with transport of wastes from the site. In addition, disposal of wastes at a remote facility does not destroy the wastes, but only relocates them.

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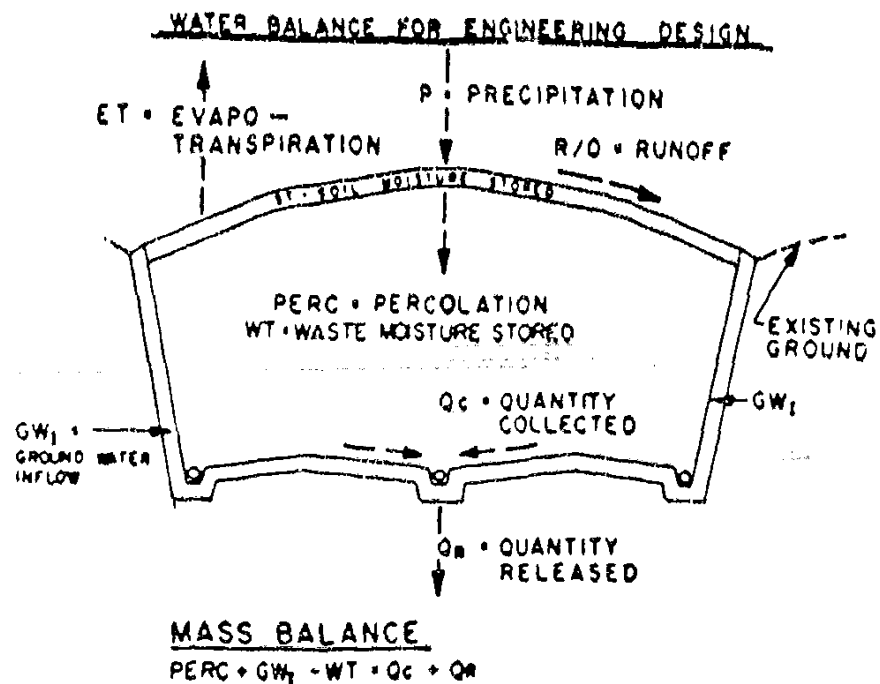
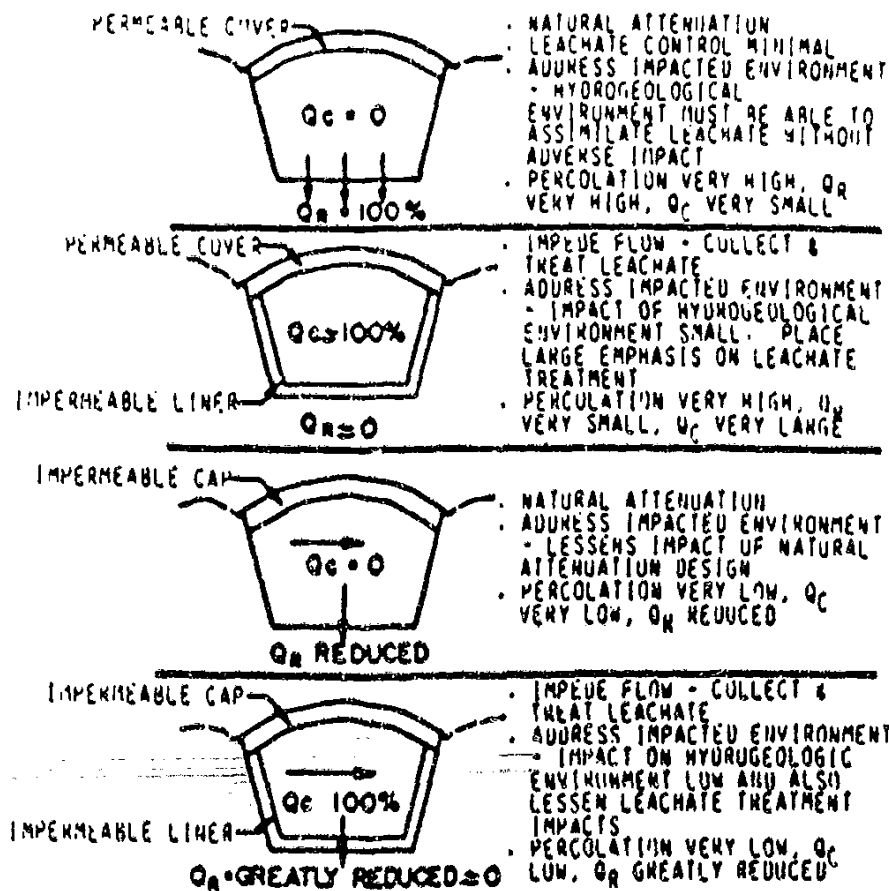


Figure 2.19. Moisture components of landfills (Smith, 1983).



Four combinations of capping and liners (Smith, 1983).

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APPENDIX C
DETAILED COST ESTIMATES
FEASIBILITY STUDY
SOUTH CAVALCADE SITE
HOUSTON, TEXAS

008351

Prepared for:
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PREVIOUSLY OPERATED PROPERTY
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440 COLLEGE PARK DRIVE
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Project No. 157373-12

AUGUST 1988

TABLE C-1
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 1

EQUIPMENT COST	CAPITAL COST
1. Deep Well Installed	\$50,000
2. Signs	\$1,000
3. Health and Safety During Construction Four weeks @ \$4,000/week	\$16,000
4. Baseline Soil Sampling 10 samples @ \$935/sample	\$9,350
Capital Cost	\$76,350
Contingency Allowances (25% of Capital Costs)	\$19,088
TOTAL CAPITAL COSTS	\$95,438

008352

TABLE C-2

ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 1

NO ACTION ALTERNATIVE
(Based on 365 Operating Days Annually)

	ANNUAL COST
A. ANALYSES	
1. Sample Collection Cost \$400/ man-day @ 12 man days plus travel	\$8,800
2. Monitoring Well Analyses (PAH and Metals @ \$935/well Twice per year from 6 wells)	\$11,220
3. Soil Analyses PAH and Metals @ \$935/sample one time a year from three locations	\$2,805
SUBTOTAL A	\$22,805
B. REPLACEMENT COSTS	
1 Well casing replacement	\$5,000
SUBTOTAL B	\$5,000
TOTAL ANNUAL OPERATING COSTS (A+B)	\$27,825
PRESENT WORTH FOR ALTERNATIVE 1 NO ACTION (10% INTEREST RATE AND 30 YEAR DURATION)	\$384,000

TABLE C-3
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 2

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
A. STABILIZATION				
1. Break Up Soil	30,000	CY	\$8.00	\$240,000
2. Mixing and Stabilization	45,000	TONS	\$200.00	\$9,000,000
3. Surface Compact	15,500	SY	\$2.00	\$31,000
SUBTOTAL A STABILIZATION COSTS				\$9,271,000
B. CONCRETE CAP				
1. Site Preparation	15,500	SY	\$1.50	\$23,250
2. Aggregate Base (12 inch high)	15,500	SY	\$5.00	\$77,500
3. Vapor Barrier	15,500	SY	\$.50	\$7,750
4. Concrete Pavement (8 inch thick)	15,500	SY	\$25.00	\$387,500
SUBTOTAL B-CONCRETE CAP				\$496,000
C. INDIRECT COSTS				
1. Engineering Costs (5% of A+ B)				\$490,000
2. Adminstration (5% of A+B)				\$490,000
3. Laboratory & Pilot Study				\$100,000
4. Construction Management (5% of A+B)				\$490,000
5. Laboratory Analysis (100 samples @ \$935/sample)				\$93,500
SUBTOTAL C				\$1,663,500
Capital Costs				\$11,430,500
Contingency Allowances (25% of Capital Costs)				\$2,858,000
TOTAL CAPITAL COSTS ALTERNATIVE 3				\$14,288,500

008354

TABLE C-4
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 2
(Based on 365 Operating Days Annually)

	ANNUAL COSTS
A. MAINTENANCE	
1. Concrete Cap (10% of Subtotal B Concrete Capital Costs)	\$50,000
SUBTOTAL A	\$50,000
TOTAL ANNUAL OPERATING COSTS A	\$50,000
PRESENT WORTH FOR ALTERNATIVE 2 (10% INTEREST RATE AND 30 YEAR DURATION)	\$14,800,000

008355

**TABLE C-5
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 3**

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
A. EXCAVATION				
1. Excavation	30,000	CY	\$8.00	\$240,000
2. Import Fill	30,000	CY	\$5.00	\$150,000
3. Backfill /Seed	30,000	CY	\$4.00	\$120,000
SUBTOTAL A EXCAVATION				\$510,000
B. OFF-SITE LANDFILL				
1. Disposal @20 Tons/Load Hauling 150 miles @ \$4/Miles	2250	LOADS	\$600.00	\$1,350,000
2. Material Disposal	45,000	TONS	\$125.00	\$5,625,000
SUBTOTAL B OFF-SITE LANDFILL				\$6,975,000
C. INDIRECT COSTS				
1. Engineering Costs 10% of A				\$51,000
2. Administration [10% of (A+B less disposal fee)]				\$186,000
3. Construction Management [10% of (A+B less disposal fee)]				\$186,000
4. Laboratory Analysis 100 samples @ \$935/sample				\$93,500
SUBTOTAL C INDIRECT COSTS				\$516,500
Capital Costs (A+B+C)				\$8,001,500
Contingency Allowances (25% of Capital Costs)				\$2,000,000
TOTAL CAPITAL COSTS ALTERNATIVE 3				\$10,000,000
THERE ARE NO O & M COSTS ASSOCIATED WITH THIS ALTERNATIVE				
PRESENT WORTH FOR ALTERNATIVE 3 (10% INTEREST RATE AND 30 YEAR DURATION)				\$10,000,000

TABLE C-6

**SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 4
SOIL WASHING TREATMENT OPTION**

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
A. MATERIAL HANDLING				
1. Excavate	30,000	CY	\$8.00	\$240,000
2. Mixing & Handling	30,000	CY	\$15.00	\$450,000
3. Backfill & Compact	32,000	CY	\$3.50	\$120,000
SUBTOTAL A MATERIAL HANDLING				\$810,000
B. SOIL WASHING				
1. Treatment System Mobilization /Demobilization	1	LS	\$15,000.00	\$15,000
2. Treatment Equipment Rental	60	MO	\$58,000.00	\$3,480,000
3. Operating Materials	1	LS	\$50,000.00	\$50,000
4. Miscellaneous	1	LS	\$40,000.00	\$40,000
SUBTOTAL B SOIL WASHING				\$3,585,000
C. INDIRECT COSTS				
1. Engineering Costs (10% of A+B)				\$440,000
2. Administration (15% of A+B)				\$660,000
3. Laboratory Analysis (100 samples @\$935/sample)				\$93,500
SUBTOTAL C INDIRECT COSTS				\$1,193,500

008357

TABLE C-6 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 4
SOIL WASHING TREATMENT OPTION

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
Capital Costs (A+B+C)				\$5,588,500
Contingency Allowances(25% of Capital Costs)				\$1,397,000
TOTAL CAPITAL COSTS ALTERNATIVE 4 SOIL WASHING TREATMENT OPTION				\$6,986,000
THERE ARE NO O&M COST ASSOCIATED WITH THIS ALTERNATIVE				
PRESENT WORTH FOR ALTERNATIVE 4 SOIL WASHING TREATMENT OPTION (10% INTEREST RATE AND 30 YEAR DURATION)				\$7,000,000

008358

TABLE C-7
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 4
ON-SITE INCINERATION TREATMENT OPTION

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
A. MATERIAL HANDLING				
1. Excavate	30,000	CY	\$8.00	\$240,000
2. Mixing & Handling	30,000	CY	\$15.00	\$450,000
3. Import Fill	10,000	CY	\$4.00	\$40,000
4. Backfill & Compact	30,000	CY	\$3.50	\$105,000
SUBTOTAL A MATERIAL HANDLING				\$835,000
B. ON-SITE INCINERATION				
1. Treatment System Mobilization / Demobilization	1	LS	\$15,000.00	\$15,000
2. Treatment Equipment Rental	30,000	CY	\$200.00	\$6,000,000
SUBTOTAL B ON-SITE INCINERATION				\$6,015,000
C. INDIRECT COSTS				
1. Engineering Costs (5% of A+B)				\$340,000
2. Administration (15% of A+B)				\$1,000,000
3. Samples Analyses (100 samples @ \$935/sample)				\$93,500
SUBTOTAL C INDIRECT COSTS				\$1,433,500

656800

TABLE C-7 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 4
ON-SITE INCINERATION TREATMENT OPTION

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
Capital Costs (A+B+C)				\$8,283,500
Contingency Allowances(25% of Capital Costs)				\$2,071,000
TOTAL CAPITAL COSTS ALTERNATIVE 4 ON-SITE INCINERATION TREATMENT OPTION				\$10,354,000
THERE ARE NO O&M COST ASSOCIATED WITH THIS ALTERNATIVE				
PRESENT WORTH FOR ALTERNATIVE 4 ON-SITE INCINERATION TREATMENT OPTION (10% INTEREST RATE AND 30 YEAR DURATION)				\$10,400,000

008360

TABLE C-3

**SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 5
BIORECLAMATION SOIL TREATMENT OPTION**

EQUIPMENT	QUANTITY	UNIT	UNIT COST	CAPITAL COST
A. INSTALIATION				
1. Excavate trenches	500	LF	\$3.00	\$1,500
2. Install and Cover Pipe	500	LF	\$5.00	\$2,500
2. Install Percolation Pipe	8,900	LF	\$2.00	\$17,800
4. Surface Cover	3,200	CY	\$10.00	32,000
5. Install Fence	4,300	LF	\$15.00	<u>\$64,500</u>
SUBTOTAL A INSTALLATION COSTS				\$118,300
B. DISPOSAL				
1. Material Disposal	85	TONS	\$125.00	\$10,600
2. Hauling 150 miles @ \$4/mile	5	LOADS	\$600.00	\$3,000
3. Repair Pavement	800	SF	\$20.00	<u>\$16,000</u>
SUBTOTAL B DISPOSAL COSTS				\$29,600
C. INDIRECT				
1. Engineering (10% A&B)				\$15,000
2. Administration (10% A&B)				\$15,000
3. Construction Management (10% A&B)				\$15,000
4. Laboratory analysis 100 Samples @ \$935/Sample				\$93,500
5. Pilot Study				<u>\$100,000</u>
SUBTOTAL C INDIRECT COSTS				\$238,500

008361

TABLE C-8 (continued)

**SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 5
BIORECLAMATION SOIL TREATMENT OPTION**

EQUIPMENT	QUANTITY	UNIT	UNIT COST	CAPITAL COST
Capital Costs (A+B+C)				\$386,400
Contingency Allowances (25% of Capital Costs)				\$96,600
TOTAL CAPITAL COSTS				\$483,000

008362

TABLE C-9
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 5
BIORECLAMATION SOIL TREATMENT OPTION

	ANNUAL COSTS
A. MAINTENANCE	
1. Miscellaneous cost (fence, percolation pipe, etc.)	<u>\$5,000</u>
SUBTOTAL A MAINTENANCE	\$5,000
 TOTAL ANNUAL OPERATING COST A	 \$5,000
 PRESENT WORTH FOR ALTERNATIVE 5 BIORECLAMATION SOIL TREATMENT OPTION	 \$530,000

008363

TABLE C-10
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 5
SOIL FLUSHING TREATMENT OPTION

EQUIPMENT	QUANTITY	UNIT	UNIT COST	CAPITAL COST
A. INSTALLATION				
1. Excavate trenches	500	LF	\$3.00	\$1,500
2. Install and Cover Pipe	500	LF	\$5.00	\$2,500
2. Install Percolation Pipe	8,900	LF	\$2.00	\$17,800
4. Surface Cover	3,200	CY	\$10.00	32,000
5. Install Fence	4,300	LF	\$15.00	<u>\$64,500</u>
SUBTOTAL A INSTALLATION COSTS				\$118,300
B. DISPOSAL				
1. Material Disposal	85	TONS	\$125.00	\$10,600
2. Hauling 150 miles @ \$4/mile	5	LOADS	\$600.00	\$3,000
3. Repair Pavement	800	SF	\$20.00	<u>\$16,000</u>
SUBTOTAL B DISPOSAL COSTS				\$29,600
C. INDIRECT				
1. Engineering (10% A&B)				\$15,000
2. Administration (10% A&B)				\$15,000
3. Construction Management (10% A&B)				\$15,000
4. Laboratory analysis 100 Samples @ \$935/Sample				\$193,500
5. Pilot Study				<u>\$100,000</u>
SUBTOTAL C INDIRECT COSTS				\$238,500

008364

TABLE C-10 (continued)

**SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 5
SOIL FLUSHING TREATMENT OPTION**

EQUIPMENT	QUANTITY	UNIT	UNIT COST	CAPITAL COST
Capital Costs (A+B+C)				\$386,400
Contingency Allowances (25% of Capital Costs)				\$96,600
TOTAL CAPITAL COSTS				\$483,000

008365

TABLE C-11
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 5
SOIL FLUSHING SOIL TREATMENT OPTION

	ANNUAL COSTS
A. MAINTENANCE	
1. Miscellaneous cost (fence, percolation pipe, etc.)	<u>\$5,000</u>
SUBTOTAL A MAINTENANCE	\$5,000
 TOTAL ANNUAL OPERATING COST A	 \$5,000
 PRESENT WORTH FOR ALTERNATIVE 5 SOIL FLUSHING SOIL TREATMENT OPTION	 \$530,000

008366

TABLE C-12
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 6

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
A. EXCAVATE				
1. Excavate	30,000	CY	\$8.00	\$240,000
2. Import Fill	30,000	CY	\$5.00	\$150,000
3. Backfill /Seed	30,000	CY	\$4.00	\$120,000
SUBTOTAL A EXCAVATE				\$510,000
B. OFF-SITE INCINERATION				
1. Hauling 25 miles @ \$4/mile	2,300	LOADS	\$100.00	\$230,000
2. Incinerate Soil	30,000	CY	\$1500.00	\$45,000,000
SUBTOTAL B OFF-SITE INCINERATION				\$45,230,000
C. INDIRECT				
1. Engineering (1% A&B)				\$635,000
2. Administration (5% A&B)				\$3,175,000
3. Laboratory analysis 100 Samples @ 935/sample				\$93,500
SUBTOTAL C INDIRECT				\$3,903,500
Capital Costs (A+B+C)				\$49,643,500
Contingency Allowances (25% of Capital Costs)				\$12,411,000
TOTAL CAPITAL COST				\$62,055,000
THERE IS NO O&M COSTS ASSOCIATED WITH THIS ALTERNATIVE				
PRESENT WORTH FOR ALTERNATIVE 6 (10% INTEREST RATE AND 30 YEAR DURATION)				\$62,000,000

008367

TABLE C-13
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 7

EQUIPMENT COST		QUANTITY	UNIT	UNIT COST	CAPITAL CAPITAL COST
<hr/>					
A.	Collection and Recharge Systems				
1.	Deep Well Installed				\$50,000
2.	Excavate Trenches	8,400	LF	\$1/LF	\$8,400
3.	Install Trench Piping	10,300	LF	\$4/LF	\$41,200
4.	Cover Pipe Clean Fill	950	CY	\$10/CY	\$9,500
5.	Pavement Demolition	750	SF	\$12/SF	\$9,000
6.	Pavement Repair	750	SF	\$20/SF	\$20,000
7.	Material Disposal	1400	tons	\$125/ton	\$175,000
8.	Disposal Hauling	70	loads	\$600/load	\$42,000
9.	Well Casings (108 @ \$5,000/casing)				\$540,000
10.	Pumps (non centrifugal) (108 @ \$7,000/pump)				\$756,000
11.	Pump Piping				\$60,000
<hr/>					
COLLECTION AND RECHARGE SYSTEM DIRECT COST					\$1,711,100
<hr/>					
Indirect Cost					
1.	Engineering Costs (10% of A&B)				170,000
2.	Administration (10% of A&B)				170,000
3.	Construction Management (10% of A&B)				170,000
<hr/>					
TOTAL COLLECTION AND RECHARGE SYSTEM INDIRECT COSTS					\$510,000
<hr/>					
SUBTOTAL A COLLECTION AND RECHARGE SYSTEM					\$2,221,100

008368

TABLE C-13 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 7

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL CAPITAL COST
B. Physical/Chemical Separation System				
1. Equalization Tank 5,000 gallons				\$30,000
2. API Separator				\$126,000
3. Dehydrator 5,000 gallons				\$15,000
4. Effluent Tank 3,000 gallons				\$15,000
5. Nutrient Equalization Tank 5,000 gallons				\$20,000
6. Polymer System				\$15,000
7. Polymer Pumps				\$3,500
8. pH Adjustment System				\$10,000
9. pH Pumps				\$5,000
10. Sludge Pumps				\$6,500
11. Effluent Pumps				\$7,500
12. Air Compressors (2) 100 cfm @ 25 HP				\$16,000
13. Instrument Air Dryer (2)				\$13,500
14. Piping				\$75,000
15. Electrical				\$15,000
16. Instrumentation				\$18,000
17. Foundations and Concrete Work				\$35,000
18. Building				\$60,000

**TOTAL PHYSICAL/CHEMICAL
SEPARATION SYSTEM DIRECT COSTS**

\$486,500

TABLE C-13 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 7

EQUIPMENT COST	QUANTITY	UNIT	UNIT COST	CAPITAL COST
1. Engineering (10% of Direct Cost)				\$48,000
2. Construction Equipment Rental (Lump Sum)				\$10,000
3. Construction Supervision (Lump Sum)				\$5,000
4. Start-Up (Lump Sum)				\$3,000
TOTAL PHYSICAL/CHEMICAL SEPARATION SYSTEM INDIRECT COSTS				\$66,000
SUBTOTAL B OIL/WATER SEPARATION SYSTEM				\$552,500
C. Miscellaneous Costs				
1. Costs of Health and Safety Requirements During Construction				\$16,000
2. State and Local Fees, Permits, etc.				\$5,000
SUBTOTAL C MISCELLANEOUS COSTS				\$21,000
CAPITAL COSTS (A+B+C)				\$2,800,000
Contingency Allowances (25% of capital costs)				\$700,000
TOTAL CAPITAL COSTS ALTERNATIVE 7				\$3,500,000

008370

TABLE C-14
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 7
(Based on 365 Operating Days Annually)

	ANNUAL COST
A. CHEMICALS	
1. Polymer (\$130/day)	\$47,500
2. Hydrogen Peroxide @ 50% (24 lb/day @ \$0.3225/lb)	\$3,000
3. Sodium Nitrate (18 lb/day @ \$34.50/100lbs)	\$3,300
SUBTOTAL A	\$53,000
B. ELECTRICITY	
1. 64,000 kwh @ \$0.06/kwh (Assumes 8 hour operation)	\$4,000
SUBTOTAL B	\$4,000
C. SLUDGE DISPOSAL	
1. 150 tons @ \$225/ton	\$33,750
SUBTOTAL C	\$33,750
D. MAN POWER	
1. Operator 8 hour/day @ \$25/hour	\$73,000
2. Guard 12 hour/day @ \$18/hour	\$78,840
SUBTOTAL D	\$151,840

008371

TABLE C-14 (CONTINUED)

SOUTH CAVALCADE SITE

ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 7
(Based on 365 Operating Days Annually)

	ANNUAL COST
E. ANALYSES	
1. Monitoring Well Analyses (10 wells @ \$935/well per year)	\$9,350
2. Collection of Samples	\$8,800
3. Replacement of casings (\$5,000/year)	\$5,000
4. Treatment System Effluent Sampling (\$48,600/year)	\$48,600
SUBTOTAL E	\$71,750
F. MAINTENANCE	
1. Two Percent of Groundwater Treatment System Cost	\$10,850
SUBTOTAL F	\$10,850
TOTAL ANNUAL OPERATING COSTS (A+B+C+D+E+F)	\$325,190
PRESENT WORTH FOR ALTERNATIVE 7 (10% INTEREST RATE AND 30 YEAR DURATION)	\$6,500,000

008372

TABLE C-15

**SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 1**

EQUIPMENT COST				CAPITAL COST
<hr/>				
A.	Collection and Recharge Systems			
1.	Deep Well Installed			\$50,000
2.	Excavate Trenches	8,400	LF	\$1/LF \$8,400
3.	Install Trench Piping	10,300	LF	\$4/LF \$41,200
4.	Cover Pipe Clean Fill	950	CY	\$10/CY \$9,500
5.	Pavement Demolition	750	SF	\$12/SF \$9,000
6.	Pavement Repair	750	SF	\$20/SF \$20,000
7.	Material Disposal	1400	tons	\$125/ton \$175,000
8.	Disposal Hauling	70	loads	\$600/load \$42,000
9.	Well Casings (108 @ \$5,000/casing)			\$540,000
10.	Pumps (non centrifugal) (108 @ \$7,000/pump)			\$756,000
11.	Pump Piping			\$60,000
<hr/>				
COLLECTION AND RECHARGE SYSTEM DIRECT COST				\$1,711,100
<u>Indirect Cost</u>				
1.	Engineering Costs (10% of A&B)			170,000
2.	Administration (10% of A&B)			170,000
3.	Construction Management (10% of A&B)			170,000
<hr/>				
TOTAL COLLECTION AND RECHARGE SYSTEM INDIRECT COSTS				\$510,000
<hr/>				
SUBTOTAL A COLLECTION AND RECHARGE SYSTEM				\$2,221,100

TABLE C-15 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 1

EQUIPMENT COST	CAPITAL COST
B. Site Groundwater Treatment System	
1. Equalization Tanks 5,000 gallons	\$30,000
2. API Separator	\$126,000
3. Dehydrator 5,000 gallons	\$15,000
4. Effluent Tank 3,000 gallons	\$15,000
5. Nutrient Equalization Tank 5,000 gallons	\$20,000
6. Polymer System	\$15,000
7. Polymer Pumps	\$3,500
8. pH Adjustment System	\$10,000
9. pH Pumps	\$5,000
10. Granular Media Filtration	\$20,000
11. Carbon Feed Tank 3,000 gallons	\$15,000
12. Carbon Feed Pumps	\$9,500
13. Carbon Unit	\$90,000
14. Sludge Pumps	\$6,500
15. Effluent Pumps	\$7,500
16. Air Compressors (2) 100 cfm @ 25 HP	\$16,000
17. Instrument Air Dryer (2)	\$13,500

TABLE C-15 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 1

EQUIPMENT COST		CAPITAL COST
18.	Piping	\$95,000
19.	Electrical	\$35,000
20.	Instrumentation	\$40,000
21.	Foundations and Concrete Work	\$56,000
22.	Building	\$65,000
Total On Site Groundwater Treatment System Direct Costs		\$708,500
1.	Engineering (10% of Direct costs)	\$75,000
2.	Construction Equipment Rental (Lump Sum)	\$10,000
3.	Construction Supervision (Lump Sum)	\$5,000
4.	Start-Up (Lump Sum)	\$3,000
Total On Site Groundwater Treatment System Indirect Costs		\$93,000
SUBTOTAL C ON-SITE GROUNDWATER TREATMENT SYSTEM		\$801,500

008375

TABLE C-15 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 1

EQUIPMENT COST	CAPITAL COST
<hr/>	
C. Miscellaneous Costs	
1. Costs of Health and Safety Requirements During Construction	\$16,000
2. State and Local Fees, Permits, etc.	\$5,000
	<hr/>
SUBTOTAL C MISCELLANEOUS COSTS	\$21,000
CAPITAL COSTS (A+B+C)	\$3,043,600
Contingency Allowances (25% of capital costs)	\$761,000
TOTAL CAPITAL COSTS ALTERNATIVE 8 GROUNDWATER TREATMENT OPTION 1	\$3,805,000

008376

TABLE C-16
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 1
(Based on 365 Operating Days Annually)

	ANNUAL COST
A. CHEMICALS	
1. Polymer (\$130/day)	\$47,500
2. Surfactants (130 lb/day @ \$1.76/day)	\$83,500
3. Carbon Replacement (70,000 lbs/year @ \$1.00/lb)	\$70,000
SUBTOTAL A	\$201,000
B. ELECTRICITY	
1. 131,000 kwh @ \$0.06/kwh (Assumes 8 hour compressor operation)	\$7,860
SUBTOTAL B	\$7,860
C. SLUDGE DISPOSAL	
1. 150 tons @ \$225/ton	33,750
SUBTOTAL C	\$33,750
D. MAN POWER	
1. Operator 8 hour/day @ \$25/hour	73,000
2. Guard 12 hour/day @ \$18/hour	78,840
SUBTOTAL D	\$151,840

TABLE C-16 (CONTINUED)
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 1
(Based on 365 Operating Days Annually)

	ANNUAL COST
E. ANALYSES	
1. Monitoring Well Analyses (10 wells @ \$935/well per year)	9,350
2. Collection of Samples	8,800
3. Replacement of casings (\$5,000/year)	5,000
4. Treatment System Effluent Sampling (\$48,600/year)	48,600
SUBTOTAL E	\$71,750
F. MAINTENANCE	
1. Two Percent of Groundwater Treatment System Cost	\$16,000
SUBTOTAL F	\$16,000
TOTAL ANNUAL OPERATING COSTS (A+B+C+D+E+F)	\$482,220
PRESENT WORTH FOR ALTERNATIVE 8 GROUNDWATER TREATMENT OPTION 1 (10% INTEREST RATE AND 30 YEAR DURATION)	\$8,300,000

008378

TABLE C-17

**SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 2**

EQUIPMENT COST				CAPITAL COST
A. Collection and Recharge Systems				
1.	Deep Well Installed			\$50,000
2.	Excavate Trenches	8,400	LF \$1/LF	\$8,400
3.	Install Trench Piping	10,300	LF \$4/LF	\$41,200
4.	Cover Pipe Clean Fill	950	CY \$10/CY	\$9,500
5.	Pavement Demolition	750	SF \$12/SF	\$9,000
6.	Pavement Repair	750	SF \$20/SF	\$20,000
7.	Material Disposal	1400	tons \$125/ton	\$175,000
8.	Disposal Hauling	70	loads \$600/load	\$42,000
9.	Well Casings (108 @ \$5,000/casing)			\$540,000
10.	Pumps (non centrifugal) (108 @ \$7,000/pump)			\$756,000
11.	Pump Piping			\$60,000
COLLECTION AND RECHARGE SYSTEM DIRECT COST				\$1,711,100
Indirect Cost				
1.	Engineering Costs (10% of A&B)			170,000
2.	Administration (10% of A&B)			170,000
3.	Construction Management (10% of A&B)			170,000
TOTAL COLLECTION AND RECHARGE SYSTEM INDIRECT COSTS				\$510,000
SUBTOTAL A COLLECTION AND RECHARGE SYSTEM				\$2,221,100

TABLE C-17 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 2

EQUIPMENT COST		CAPITAL COST
B. On-Site Groundwater Treatment System		
1.	Equalization Tanks 5,000 gallons	\$30,000
2.	API Separator	\$126,000
3.	Dehydrator 5,000 gallons	\$15,000
4.	Effluent Tank 3,000 gallons	\$15,000
5.	Nutrient Equalization Tank 5,000 gallons	\$20,000
6.	Polymer System	\$15,000
7.	Polymer Pumps	\$3,500
8.	pH Adjustment System	\$10,000
9.	pH Pumps	\$5,000
10.	Air Stripping Feed Tank 3,000 gallons	\$15,000
11.	Air Stripper Feed Pumps	\$9,500
12.	Air Stripping Column	\$30,000
13.	Granular Media Filtration	\$20,000
14.	Carbon Feed Tank 3,000 gallons	\$15,000
15.	Carbon Feed Pumps	\$9,500
16.	Carbon Unit	\$90,000
17.	Sludge Pumps	\$6,500

008380

TABLE C-17
(CONTINUED)

SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 2

EQUIPMENT COST		CAPITAL COST
18.	Effluent Pumps	\$7,500
19.	Air Compressors (2) 100 cfm @ 25 HP	\$16,000
20.	Instrument Air Dryer (2)	\$13,500
21.	Piping	\$110,000
22.	Electrical	\$50,000
23.	Instrumentation	\$100,000
24.	Foundations and Concrete Work	\$75,000
25.	Building	\$65,000
TOTAL ON-SITE GROUNDWATER TREATMENT SYSTEM DIRECT COSTS		\$872,000
1.	Engineering (10% of Direct Costs)	\$89,000
2.	Construction Equipment Rental (Lump Sum)	\$10,000
3.	Construction Supervision (Lump Sum)	\$5,000
4.	Start-Up (Lump Sum)	\$3,000
TOTAL ON-SITE GROUNDWATER TREATMENT SYSTEM INDIRECT COSTS		\$107,000
SUBTOTAL B ON-SITE GROUNDWATER TREATMENT SYSTEM		\$979,000

TABLE C-17
(CONTINUED)

SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 2

EQUIPMENT COST	CAPITAL COST
C. Miscellaneous Costs	
1. Costs of Health and Safety Requirements During Construction	\$16,000
2. State and Local Fees, Permits, etc.	\$5,000
SUBTOTAL C-MISCELLANEOUS COSTS	\$21,000
CAPITAL COSTS (A+B+C)	\$3,221,100
Contingency Allowances (25% of capital costs)	\$805,300
TOTAL CAPITAL COSTS ALTERNATIVE 8 GROUNDWATER TREATMENT OPTION 2	\$4,026,400

008382

TABLE C-18
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 2
(Based on 365 Operating Days Annually)

	ANNUAL COST
A. CHEMICALS	
1. Polymer (\$130/day)	\$47,500
2. Surfactants (130 lb/day @ \$1.76/day)	\$83,500
3. Carbon Replacement (63,000 lbs/year @ \$1.00/lb)	\$63,000
SUBTOTAL A	\$194,000
B. ELECTRICITY	
1. 160,000 kwh @ \$0.06/kwh (Assumes 8 hour compressor operation)	\$9,600
SUBTOTAL B	\$9,600
C. SLUDGE DISPOSAL	
1. 150 tons @ \$225/ton	\$33,750
SUBTOTAL C	\$33,750
D. MAN POWER	
1. Operator 8 hour/day @ \$25/hour	\$73,000
2. Guard 12 hour/day @ \$18/hour	\$78,840
SUBTOTAL D	\$151,840

TABLE C-18 (CONTINUED)
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 2
(Based on 365 Operating Days Annually)

	ANNUAL COST
E. ANALYSES	
1. Monitoring Well Analyses (10 wells @ \$935/well per year)	\$9,350
2. Collection of Samples	\$8,800
3. Replacement of casings (\$5,000/year)	\$5,000
4. Treatment System Effluent Sampling (\$48,600/year)	\$48,600
SUBTOTAL E	\$71,750
F. MAINTENANCE	
1. Two Percent of Groundwater Treatment System Cost	\$19,000
SUBTOTAL F	\$19,000
TOTAL ANNUAL OPERATING COSTS (A+B+C+D+E+F)	\$479,960
PRESENT WORTH FOR ALTERNATIVE 8 GROUNDWATER TREATMENT OPTION 2 (10% INTEREST RATE AND 30 YEAR DURATION)	\$8,500,000

TABLE C-19
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 3

EQUIPMENT COST				CAPITAL COST
A. Collection and Recharge Systems				
1. Deep Well Installed				\$50,000
2. Excavate Trenches	8,400	LF	\$1/LF	\$8,400
3. Install Trench Piping	10,300	LF	\$4/LF	\$41,200
4. Cover Pipe Clean Fill	950	CY	\$10/CY	\$9,500
5. Pavement Demolition	750	SF	\$12/SF	\$9,000
6. Pavement Repair	750	SF	\$20/SF	\$20,000
7. Material Disposal	1400	tons	\$125/ton	\$175,000
8. Disposal Hauling	70	loads	\$600/load	\$42,000
9. Well Casings (108 @ \$5,000/casing)				\$540,000
10. Pumps (non centrifugal) (108 @ \$7,000/pump)				\$756,000
11. Pump Piping				\$60,000
COLLECTION AND RECHARGE SYSTEM DIRECT COST				\$1,711,100
Indirect Cost				
1. Engineering Costs (10% of A&B)				170,000
2. Administration (10% of A&B)				170,000
3. Construction Management (10% of A&B)				170,000
TOTAL COLLECTION AND RECHARGE SYSTEM INDIRECT COSTS				\$510,000
SUBTOTAL A COLLECTION AND RECHARGE SYSTEM				\$2,221,100

TABLE C-19 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 3

EQUIPMENT COST	CAPITAL COST
B. On-Site Groundwater Treatment System	
1. Equalization Tanks 5,000 gallons	\$30,000
2. API Separator	\$126,000
3. Dehydrator 5,000 gallons	\$15,000
4. Effluent Tank 3,000 gallons	\$15,000
5. Nutrient Equalization Tank 5,000 gallons	\$20,000
6. Polymer System	\$15,000
7. Polymer Pumps	\$3,500
8. pH Adjustment System	\$10,000
9. pH Pumps	\$5,000
10. Aeration Tank 150,000 gallons	\$200,000
11. Agitators	\$38,500
12. Clarifier 100,000 gallons	\$170,000
13. Recycle Sludge Pumps	\$5,500
14. Sludge Pumps	\$6,500
15. Effluent Pumps	\$7,500
16. Air Compressors (2) 100 cfm @ 25 HP	\$16,000

008386

TABLE C-19 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 3

EQUIPMENT COST		CAPITAL COST
17.	Instrument Air Dryer (2)	\$13,500
18.	Piping	\$155,000
19.	Electrical	\$75,000
20.	Instrumentation	\$150,000
21.	Foundations and Concrete Work	\$85,000
22.	Building	\$80,000
TOTAL ON-SITE GROUNDWATER TREATMENT SYSTEM DIRECT COSTS		\$1,212,000
1.	Engineering (10% of Direct Costs)	\$120,000
2.	Construction Equipment Rental (Lump Sum)	\$10,000
3.	Construction Supervision (Lump Sum)	\$5,000
4.	Start-Up (Lump Sum)	\$3,000
TOTAL ON-SITE GROUNDWATER TREATMENT SYSTEM INDIRECT COSTS		\$138,000
SUBTOTAL B ON-SITE GROUNDWATER TREATMENT SYSTEM		\$1,380,000

008387

TABLE C-19 (CONTINUED)
SOUTH CAVALCADE SITE
DETAILED COST ESTIMATE FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 3

EQUIPMENT COST	CAPITAL COST
C. Miscellaneous Costs	
1. Costs of Health and Safety Requirements During Construction	\$16,000
2. State and Local Fees, Permits, etc.	\$5,000
SUBTOTAL C MISCELLANEOUS COSTS	\$21,000
CAPITAL COSTS (A+B+C)	\$3,592,100
Contingency Allowances (25% of capital costs)	\$898,000
TOTAL CAPITAL COSTS ALTERNATIVE 8	
GROUNDWATER TREATMENT OPTION 3	\$4,490,100

008388

TABLE C-20
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 6
GROUNDWATER TREATMENT OPTION 3
(Based on 365 Operating Days Annually)

	ANNUAL COST
A. CHEMICALS	
1. Polymer (\$130/day)	\$47,500
2. Surfactants (160 lb/day @ \$1.76/day)	\$103,500
SUBTOTAL A	\$151,000
B. ELECTRICITY	
1. 200,000 kwh @ \$0.06/kwh (Assumes 8 hour compressor operation)	\$12,000
SUBTOTAL B	\$12,000
C. SLUDGE DISPOSAL	
1. 180 tons @ \$225/ton	\$40,500
SUBTOTAL C	\$40,500
D. MAN POWER	
1. Operator 8 hour/day @ \$25/hour	73,000
2. Guard 12 hour/day @ 18/hour	78,840
SUBTOTAL D	\$151,840

008339

TABLE C-20 (CONTINUED)
SOUTH CAVALCADE SITE
ANNUAL OPERATING AND PRESENT WORTH COSTS FOR ALTERNATIVE 8
GROUNDWATER TREATMENT OPTION 3
(Based on 365 Operating Days Annually)

ANNUAL COST	
E. ANALYSES	
1. Monitoring Well Analyses (10 wells @ \$935/well per year)	9,350
2. Collection of Samples	8,800
3. Replacement of casings (\$5,000/year)	5,000
4. Treatment System Effluent Sampling (\$48,600/year)	48,600
SUBTOTAL E	\$71,750
F. MAINTENANCE	
1. Two Percent of Groundwater Treatment System Cost	\$27,000
SUBTOTAL F	\$27,000
TOTAL ANNUAL OPERATING COSTS (A+B+C+D+E+F)	\$454,110
PRESENT WORTH FOR ALTERNATIVE 8 GROUNDWATER TREATMENT OPTION 3 (10% INTEREST RATE AND 30 YEAR DURATION)	\$8,700,000

062800